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ENGINEERING REPORT ON WAVE TANK TESTS ON SPLIT PIPE.(U)
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UNCLASSIFIED TR-3 CEL-CR-78.007 NL

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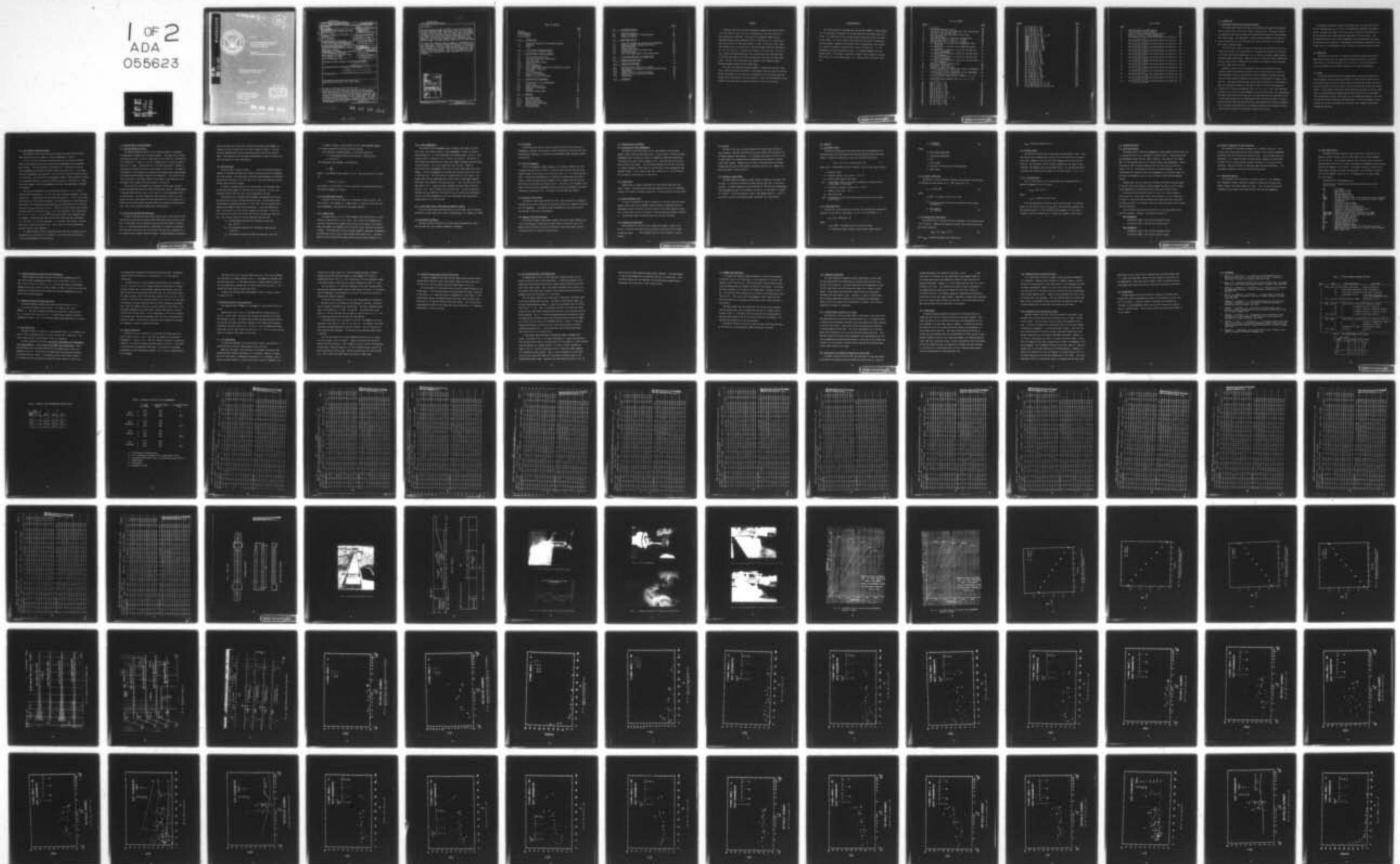

CR 78.007

CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

ENGINEERING REPORT ON WAVE TANK TESTS ON SPLIT PIPE

December 1977

An Investigation Conducted by
OREGON STATE UNIVERSITY
SCHOOL OF ENGINEERING
Corvallis, Oregon

N68305-77-C-0041

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

18 CEL REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 19 CR-78.007	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 ENGINEERING REPORT ON WAVE TANK TESTS ON SPLIT PIPE.		5. TYPE OF REPORT & PERIOD COVERED Final rept., December 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 Tokuo Yamamoto		8. CONTRACT OR GRANT NUMBER(s) 15 N68305-77-C-0041
9. PERFORMING ORGANIZATION NAME AND ADDRESS Ocean Engineering, Wave Research Facility T.R.3, School of Engineering Oregon State University, Corvallis, OR		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS YF52.556.091.01.316
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command 200 Stovall Street Alexandria, VA 22332		12. REPORT DATE 11 Dec[redacted]977
		13. NUMBER OF PAGES 122 12 125p.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Civil Engineering Laboratory Naval Construction Battalion Center Port Hueneme, CA 93043		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE 14 TR-3

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

16 F52556

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

17 YF52556091

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Wave forces, split pipe, lift, drag, inertia

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Laboratory wave tank tests were conducted to measure and record the horizontal and vertical wave forces on a prototype split pipe with nearly full scale design wave conditions. The ranges of the Reynolds number and the Keulegan-Carpenter number covered are 10^4 to $2x10^5$ and 0 to 40, respectively. The tests are done for three water depths, (4, ~~feet~~, 6 ~~feet~~ and 8 feet), → (over)

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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three wave periods (2 sec, 4 sec and 6 sec), four wave heights and four orientations (0°, 45°, 90° and -45°), of the bolting flanges of the split pipe. The lift, drag, inertia and maximum horizontal force coefficients were evaluated based on the Airy wave theory and the Morrison equations and other wave force equations. The wave force coefficients are dependent on the Reynolds number, Keulegan-Carpenter number and the flange angle.

The single most important design parameter is determined to be the flange angle. When the flanges are parallel to the bottom, both horizontal and vertical forces are minimum, but the forces are increased by up to seven times when the flanges have large angles to the flow direction. Thus, the disorientation of the flanges by the waves may be a major contributor to split pipe failures.

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ACKNOWLEDGEMENTS

This work was done in accordance with the contract N68305-77-C-0041 between the Civil Engineering Laboratory of the Navy Department and Oregon State University. Mr. John Ciani of CEL provided valuable suggestions during the course of the project. Dr. John H. Nath of OSU joined with the author in developing the test program, suggested and designed the force dynamometers, and reviewed this report for submittal, with particular input to Section 10.0. Lt. Tim Brandenburg of the Navy Engineering Corps, as a Graduate Student, Mr. Larry Crawford and Mr. Terry Dibble, laboratory engineers, have assisted in the wave tank testing. Mr. Koji Kobune and Mr. M. C. Chen assisted in the data reduction.

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1.0 INTRODUCTION

1.1 Background Information and Problem Statement

The primary means used by the Navy for protecting and immobilizing submarine cables is split pipe. This pipe is shown in Figure 1 which illustrates the bolting together of the upper and lower half sections and the mating of the assembled full pipe sections. The approximate inside and ouside diameters of the main portion of the pipe are 3.5 in. (ID) and 5.0 in. (OD), which does not include the bell ends or bolting flanges.

Plain pipelines, which do not have the bell ends and flanged sides that characterize split pipe, are used extensively in engineered construction in the ocean by civilian and military organizations for oil and gas transport, sewage disposal and other common applications. Submarine cables for power and signal transmission are also widely used in industry and the military, but these are often protected by burial rather than split pipe.

Submarine pipelines must be designed to resist the hydrodynamic forces caused by waves which depend on the water particle accelerations and velocities. The hydrodynamic forces on pipelines are usually estimated by the Morrison equations or similar empirical equations with empirical coefficients of inertia, drag and lift. The force coefficients must be derived from laboratory or field experiments on pipe sections under the influence of waves or similar flow conditions. Virtually all of the past experiments (Ref. 1, 2, 4, 5, 6, 7, 8) of this type have involved plain circular cylinder shaped pipe but never split pipe. As a consequence, the coefficients derived from these tests are applicable to plain pipelines but not to split pipe because the flow around shapes other than plain cylinders is significantly different from that around plain pipe and therefore the forces are different. Thus, the force coefficients that are presently available for the design of "pipelines" cannot be applied to the design of lines of split pipe.

Furthermore, the bolting flanges of the split pipe will act like airfoils. The lift and drag forces on an airfoil are dramatically changed by the angle of attack. Although the flanges of the split pipe are usually laid horizontally at the installation, the flange angles may change due to the wave action. The increased wave forces, due to the re-orientation of the flange angle, may cause the failure of split pipelines. The quantitative information on the effect of the flange angle on the hydrodynamic forces on the split pipe has not been available.

1.2 Objectives

The purpose of this work is to measure and record horizontal and vertical wave forces on split pipe in a wave tank and reduce these data to give force coefficients of inertia, drag and lift for split pipe. Special attention is given to the effect of the flange orientation on the force coefficients.

1.3 Scope

At the Wave Research Facility at Oregon State University, wave tank tests are performed on the test section consisting of a three-section length of split pipe under various conditions of water depth, wave height and period, and inclination of the plane of the pipe flanges relative to the bottom of the tank (flange angle). The horizontal and vertical forces imposed by the waves on the test pipe section are measured and recorded along with the characteristics of the waves. Force coefficients of drag, inertia and lift are derived and reported. This work includes the design, fabrication and installation of the test equipment; the performance of the tests; the reduction of the data; and a separate report which includes the raw data.

2.0 TEST SCHEDULE AND MODIFICATIONS

The schedule of wave tank tests and the actual work done during the three weeks period of July 18 to August 5, 1977 are summarized in Table 1.

On July 21, 1977, during the installation of the test pipe force dynamometer unit at the wave tank, one of the two force dynamometers was accidentally bent slightly. This was immediately reported to CEL. Calibration of the two force dynamometers was made to see their response characteristics. It was found that both dynamometers gave excellent linear response in both horizontal and vertical directions. Only the bent force dynamometer showed a slight response to torque. (For a detailed discussion, read the calibration results in Section 6.3.) Since no critical damage to the force dynamometer was found, the experiments proceeded as scheduled.

The nine test combinations of the three water depths, h = 4', 6' and 8', and the three flange angles ϕ = 0°, 45°, 90°, were originally scheduled. For each combination, twelve waves with the three wave periods, T = 2 sec. 4 sec, 6 sec, and the four wave heights were scheduled. For each combination of water depth and wave period, the clean maximum wave height H_{max} was determined by trial and error. The values of H_{max} are given in Table 3. Then the four wave heights were selected by taking 100, 75, 50 and 25% of H_{max}. All of the scheduled 11 test combinations (h = 4', 6', 8' and ϕ = 0°, 45°, 90° and two duplications) were completed ahead of schedule. Since some wave tank time was left, three more test combinations (ϕ = -45° for h = 4', 6', 8') were made. ϕ = -45° means that flange at the wave board side is down at an angle of 45°. Thus, a total of 14 test combinations, totaling 168 runs, were conducted.

Lt. Robert Steimer from CEL inspected the wave tank tests on August 2 and 3. He observed test series No. 12, 13,14 (Run No. 133 to 168) and the calibration of the force dynamometers after the tests.

3.0 DESCRIPTION OF TESTING APPARATUS

3.1 OSU Wave Research Facility

The OSU Wave Research Facility is on an open site which is convenient to many types of research and is shown in Figure 2. The major unit is a wave and towing basin which is 104.27 m long (342'), 3.66 m wide (12') and generally 4.57 m deep (15'). Usually a 1 m (3.3') freeboard exists so that the water is 3.66 m (11.7') deep. The wave board is a flap-type board which is hinged at the bottom in a section which has a total depth of 5.49 m (18'). The board is activated by a 150 hp pump with a hydraulic servo mechanism which was designed and installed by MTS Systems Corporation of Minneapolis. The facility is the first to be built in the United States to have water on one side only of the wave board, which reduces the required power to activate it.

The facility has the capability of producing solitary waves, periodic waves and random waves which will model the ocean wave spectra. Breaking waves in the deep water section of up to 1.52 m high (5') can be generated as well as smaller waves. The wave frequencies range from about 0.25 cps to 1 cps. Several pre-cast concrete panels are available which are 3.66 m square (12'). These are used to help modify the water depth and to construct the beach section. Thus, various bottom configurations can be obtained.

3.2 False Floor and Beach Configurations

In order to maximize the wave induced bottom current, the false floor was constructed by the pre-cast concrete panels which were securely bolted to the wall 3.5 feet above the tank bottom and covering 120 feet length as shown in Fig. 3. In the end 96 feet section, a beach with 1/12 slope was constructed. The front end of the false floor and the tank floor were also connected by a 1/12 slope to form a smooth transition section. The gaps between the concrete

panels and walls were sealed with T-section and L-section steel members to prevent flow leaks through the false floor as shown in Figure 4. The test pipe was located 42 feet from the transition section and 78 feet from the beach. The reflection from this beach configuration is known to be small and less than about 5% for most wave periods.

3.3 Test Split Pipe

The split pipe is shown in Figure 1 which illustrates the bolting together of the upper and lower half sections and the mating of the assembled full pipe sections. The approximate inside and outside diameters of the middle portion of the pipe are 3.5 in. (ID) and 5.0 in. (OD), which does not include the bell ends or bolting flanges.

In order to evaluate the wave force coefficients, the displaced volume and the equivalent diameter of the split pipe are required. For this, the displaced volume of the test split pipe was measured as follows:

Two halves of split pipe were bolted together and openings at the sides and the ends were tightly shielded with masking tape. The displaced volume was measured by submerging the pipe in a 13.5" (ID) x 40 inch container and measuring the change in water surface elevations. Since the container was small, the volume of the split pipe was measured in two steps: first, the half including the outer bell end and then the half including the inner bell end. The volumes of each half and the inner bell ends only are:

$\forall_1$ = the displaced volume the half including an outer bell end = 474 in^3

$\forall_2$ = the displaced volume the half including a middle portion = 832.0 in^3

$\forall_3$ = the displaced volume of an inner bell end only = 161.0 in^3.

As shown in Figure 5, the six halves of split pipe assembled together as a three jointed unit were used as the test section.

Thus, the total displaced volume, $\forall$, of the test section is:

$\forall$ = the displaced volume of test section = $3(\forall_1+\forall_2-\forall_3)+\forall_3$

$\forall = 3113.0 \text{ in}^3$.

The "equivalent" pipe diameter D was defined by

$$\forall = \frac{\pi D^2}{4} l$$

where l = the length of test section = 112 in. Thus, the value of D is given as:

$$D = (4\forall/\pi l)^{\frac{1}{2}} = 5.95 \text{ in.}$$

The values $\forall = 3113 \text{ in}^3$ and D = 5.95 in. were used to calculate the force coefficients throughout this report.

3.4 Force Measurement Devices

The details of the test setup are illustrated in Figures 4 and 5. The test section is the assembly of a support pipe, six halves of split pipe, two force dynamometers, two shrouds and two support channels.

3.4.1 Support Pipe

The support pipe is a 3.5 in. (OD) standard steel pipe with 3/4 in. thick flanges at both ends and is 114 in. long. The six halves of prototype split pipe were clamped onto the support pipe to form a solid piece of test section. Since the support pipe (tightly) fits in the split pipe, there was no chance of slippage. The flange angle of split pipe was changed by unbolting, reassembling and rebolting the split pipe in water without moving other units. The gap between the false bottom and the lowest points of split pipe was always 0.2 in.

3.4.2 Force Dynamometers

Two identical force dynamometers were located at both ends of the test split pipe. The close up view of a force dynamometer is shown in Figure 6. They were made of 1 in. thick ALCOA 6061-T651 aluminum plate. The 6 in. long sensing section is tapered to 0.6 in. square cross section. The strains in this section were measured by foil type strain gages to measure the wave forces in two directions. Four strain gages were used to form a bridge for each direction by a dynamometer, thus total of eight strain gages per a dynamometer. The force dynamometer has slotted holes at one end and a disk plate at the other end. The disk ends were connected firmly to the flanges of the support pipe and the slotted ends were firmly bolted to the support channels which were firmly mounted to the wave tank walls. Thus, the entire test split pipe section 114 in. long was rigidly suspended from both sides of the wave tank wall and nearly reached across the wave tank. In order to better approximate the two dimensional flow condition and to minimize the hydrodynamic forces on the force dynamometers, the force dynamometers were covered with shrouds made of 8 in. (OD) PVC pipe.

3.4.3 Strain Gage Signal Conditioners and Amplifier System

The strain gage outputs were amplified by a strain gage signal conditioner and amplifier system, Model 2100, Vishay Intertechnology, Inc., MacVern, PA 19355.

3.5 Wave Height Transducers

The water surface fluctuation at the test pipe was measured by a Sonic Profiler Model 86, Sonic Systems, Minneapolis, Minnesota.

3.6 Visicorder

The horizonal and vertical forces from both the East and the West force dynamometers, together with the water surface fluctuation at the test pipe, were simultaneously recorded by a 6-channel Visicorder Model 1508, Honeywell, Denver, Colorado 80217.

3.7 Hot Film Anemometer

A hot film anemometer (Thermo Systems, Inc. system No. 1050-2C) was used to measure the horizontal velocity at 7 feet upstream from the pipe and at the elevation equal to the center line of the split pipe, i.e. 5 in. above the false floor. The velocity measurements were conducted to evaluate the force coefficients by using the measured wave kinematics and to compare them with the present results in the future (see Section 10.2). This data is not included in this report since the velocity measurements were outside the contracted work and were conducted at no expense to CEL. The data will be provided upon request.

3.8 Propeller Current Meter

A propeller current meter (Model 401 & 403, Novar Electronics, Gloucester, England) was also used to measure the horizontal velocity for comparison with the hot film anemometer. The propeller meter was mounted on the opposite side of the tank wall to the hot film anemometer.

3.9 Magnetic Tape Analog Recorder

A 14-channel magnetic tape analog recorder (Bell Howell Model CPR4010) was used to simultaneously record the horizontal force, the vertical force, the water surface elevations at the split pipe and at the current meters, and the horizontal current for possible future analysis.

4.0 DESCRIPTION OF EXPERIMENTS

4.1 Calibration of Force Dynamometers

The length of test split pipe, 112 in., was marked by nine stations, equally spaced, starting from the west end. At each station, the west and east dynamometers were calibrated in water by incremental loading and unloading of five lead bricks, each of which weighed 15 lbs., using very low friction ball bearing pulleys and cables. The calibration was made for the four directions, i.e. upward, downward, forward (North) (the direction of wave propagation) and backward (South). At the center of the pipe (station No. 5), the calibration was also made by using four 50 lb. lead bricks.

4.2 Torque Tests

Theoretically, an equally balanced four strain gage bridge should not sense a torque. The torque test was made by applying two 50 ft-lb incremented torque at the center of the pipe (station No. 5) using fixed bar and lead bricks.

4.3 Impulse Response Tests

In order to determine the natural frequencies of the test pipe-force dynamometer system, the impulse response tests were made by recording the force dynamometer signals during the free oscillation of the system induced by applying a certain load by hand at the center of the pipe and then suddenly releasing it. The tests were done in both horizontal and vertical directions.

4.4 Changing of Flange Angle

The orientation of the split pipe flanges was changed in water by two divers. A level bar and angle blocks were used to precisely set the flange at desired angles. The underwater photo of this procedure is shown in Figure 7.

4.5 Testing

For each of 168 runs, the wave and wave force signals were recorded by the visicorder. The wave, wave force and current signals were recorded by the 14-channel magnetic tape recorder. All recordings were made for the first 6 to 12 waves before the incident wave was contaminated by any possible reflected waves from the beach. Between runs, at least a five minute wait was allowed to make sure the water surface became calm before the next run. Example test waves are shown in Figures 8 and 9.

4.6 Changing of Water Depth

The water depth was changed by either adding or pumping out the water from the tank. To increase or decrease the water depth by one foot, it took about one hour. The water temperature varied from $64^{o}F$ to $70^{o}F$ during the experiments. The corresponding range of the kinematics viscosity ν of the water is $1.05x10^{-5}$ to $1.15x10^{-5}$. Since the variation is small, the average value of ν $1.10x.0^{-5}$, was used to calculate the Reynolds number throughout this investigation.

5.0 ANALYSIS

5.1 Horizontal Forces

The Morrison coefficient of drag and inertia will be determined from horizontal wave force data based on the Morrison equation and the Airy wave theory. The Morrison equation for the split pipe may be written as

$$f_H(\theta) = \rho \forall\, C_I\, \dot{u}(\theta) + \tfrac{1}{2}\rho D l\, C_D |u(\theta)| \cdot u(\theta) \quad (1)$$

where $f_H(\theta)$ = instantaneous value of horizontal force on split pipe at phase θ

ρ = density of water

$\forall$ = displaced volume of split pipes = 3113 in^3.

C_I = inertia coefficient of split pipe

$\dot{u}(\theta)$ = instantaneous value of horizontal acceleration of water particle at the center of split pipe

D = "equivalent" diameter of split pipe = 5.95 in.

l = length of split pipe = 112 in.

C_D = drag coefficient

$u(\theta)$ = instantaneous value of horizontal particle velocity at the center of split pipe.

5.1.1 Drag Coefficient

The value of C_D was evaluated at the wave crest and the wave trough from Equation (1) and the Airy wave theory, i.e. at $\theta = 0^o$, 180^o where $\dot{u} = 0$.

$$C_D = F_H(0, 180^o)/\frac{1}{2}\rho D l \quad U^2$$

where

$F_H(o, 180^o)$ = horizontal force at crest and trough

U = maximum horizontal velocity from Airy wave theory given as

$$U = \frac{\pi H}{T} \frac{\cosh k s}{\sinh k h} \tag{3}$$

where

H = wave height (measured)

T = wave period (measured)

$k = 2\pi/L$

L = wave length

s = distance of the pipe axis from tank bottom

h = water depth

5.1.2 Inertia Coefficient

The value of C_I was evaluated at the wave zero-upcrossing from Equation (1) and the Airy wave theory, at $\theta \doteq \pm 90^o$, where $u(\theta) = 0$;

$$C_I = F_H(\ 90^o)/\rho V \dot{U} \tag{4}$$

where

$F_H(\pm 90^o)$ = horizontal force at zero cross

$\dot{U}$ = maximum horizontal acceleration from the Airy wave theory and given as

$$\dot{U} = \frac{2\pi^2 H}{T^2} \frac{\cosh k s}{\sinh k h} \tag{5}$$

5.1.3 Maximum Force Coefficients

The maximum value of the wave forces are important in the design of pipe-like structures. Sometimes the maximum horizontal force coefficient may be most simply defined as

$$F_{Hmax} = \frac{1}{2} \rho\ C_{Hmax}\ D \cdot l |U| U \tag{6}$$

where C_{Hmax} = maximum horizontal force coefficient

F_{Hmax} = maximum horizontal force.

5.2 Vertical Forces

The vertical water particle acceleration near the bottom is small. Thus, the vertical force component due to the vertical acceleration will be negligibly small compared to the vertical force component due to the horizontal velocity. The horizontal velocity induces, depending on the stage of wake formation, the downward force and the upward force. For the detailed discussion about this mechanism, the readers are referred to Refs. 4, 5, 6, 7, 8.

5.2.1 Lift Coefficient

The lift coefficients C_L will be evaluated for the maximum values of upward and downward forces as follows:

$$F_{v\ max} = \frac{1}{2} \rho\ C_L\ Dl\ U^2 \tag{8}$$

where

$F_{v\ max}$ = maximum vertical forces.

Using the analog data recorded on photo-sensitive paper, for each and every run, the values of C_D, C_I, C_{Hmax} and C_L were determined together with the Reynolds number, Re = UD/ν and the period parameter K = UT/D, where ν = kinematic viscosity of water and D = "equivalent" diameter of split pipe.

6.0 CALIBRATION RESULTS

6.1 Conversion Factors

The sample plots of the force dynamometers output reading in micro-strain ($\mu\varepsilon$) vs. the applied load in lbs. are shown in Figures 10 and 11. Both the west and east dynamometers show excellent linear responses. The values of the slopes, dR/dF, of the straight lines for all loading stations were determined. The distributions of dR/dF along the length of the test split pipe are plotted in Figures 12 to 15. These plots are similar to influence diagrams. The plots indicate that the response of the force dynamometers are practically equal for the upward and downward as well as for the forward (north) and the backward (south).

Assuming that the wave forces are uniformly distributed along the length of the split pipe, the conversion factors between the forces and the readings can be determined by calculating the areas under the influence curves.

The values of the conversion factor F/R, the ratio of the reading in micro-strain ($\mu\varepsilon$) to the total force on the test pipe in lbs, are tabulated in Table 4. Since the difference between the calibrations before and after the tests were small, the averages of the two values were used in the following wave force analysis.

The calibration signals equivalent to 80.7 $\mu\varepsilon$ are always shown on the wave force records. Therefore, the signals are equal to:

West Dynamometer

calibration signal = 39.2 lbs for horizontal forces

calibration signal = 34.4 lbs for vertical forces

East Dynamometer

calibration signal = 37.2 lbs for horizontal forces

calibration signal = 38.2 lbs for vertical forces.

6.2 Natural Frequencies of Pipe Vibrations

The recording of the impulse response test is shown in Figure 16. Since the test split pipe portion was very rigid compared to the flexible dynamometers practically only the first mode of vibration exists. Thus the higher modes are negligible. It is shown that the first mode natural frequencies of the system are about 7.8 Hz in the horizontal direction and about 7.9 Hz in the vertical direction. They are one order of magnitude higher than wave frequencies. Thus the dynamic exitation of the pipe by wave should be small.

6.3 Torque Test Results

The recording of the torque test is given in Figure 17. The undamaged west dynamometer showed a negligible response to torque while the east dynamometer showed a noticeable response to torque. Thus, the data from the west dynamometer may be more reliable than the data from the east dynamometer.

7.0 WAVE FORCE RESULTS

An example visicorder output for wave force tests is given in Fig. 18. Generally, excellent data, similar to that shown in Fig. 18 were obtained for all 168 runs. The visicorder output of 168 runs and all the calibration data have been sent to CEL as a part of the August and September progress reports. They are not repeated in this report. The numerical values of various force coefficients, together with other wave parameters, are tabulated in Tables 5 to 18 as the computer printout for all 14 combinations of the water depths and flange angles.

The definition of the parameters are:

(The forces are in terms of total force on the entire test section 112 in. in lbs.)

RUN	= Run number
H	= Wave height in feet
T	= Wave period in sec.
FV+	= Maximum upward force
FV-	= Maximum downward force
FHMAX	= Maximum horizontal force in the direction of wave propagation
FHMIN	= Maximum horizontal force in the opposite direction of wave propagation
FHC	= Horizontal force at crest
FHT	= Horizontal force at trough
FH+	= Horizontal force at zero-up-cross
FH-	= Horizontal force at zero-down-cross
CL+	= Upward lift coefficient evaluated from FV+
CL-	= Downward lift coefficient from FV-
CDMAX=CHMAX	= Maximum horizontal force coefficient from FHMAX
CDMIN=CHMIN	= Maximum horizontal force coefficient from FHMIN
CDC	= Drag coefficient from FHC
CDT	= Drag coefficient from FHT
CI+	= Inertia coefficient from FH+
CI-	= Inertia coefficient from FH-
RE**5	= Reynolds number in 10^5
K	= Keulegan-Carpenter number
VEL	= Maximum horizontal velocity in ft/sec from Airy theory
ACC	= Maximum horizontal acceleration in ft/sec^2 from Airy theory
WL	= Wave length in ft.

7.1 Comparison Between the West and East Dynamometers

Example comparisons between the data from the west dynamometer and the data from the east dynamometer are shown in Fig. 19 for CDC vs. Re at $\phi = 0°$ and in Fig. 20 for CL + vs. Re at $\phi = 0°$. For the cases shown, the agreements between the two sets of data are good. However, in order to avoid any possible contamination of the data due to the torque, only the west dynamometer data are used in the following analysis.

7.2 Comparison Between the Duplicated Tests

An example comparison between the original test series No. 9 ($\phi = 0°$, h = 8 ft.) and the repeated test series No. 11 is shown in Fig. 21 for CHMAX vs. K. The similar comparison between the series No. 4 and the series No. 7 is given in Fig. 22 for CL+ vs. K. For both cases, generally excellent agreements are shown. This is an indication that the data gathered are reliable.

7.3 Drag Coefficient

The plots of CDC vs. K with the Re and the water depth, h, as parameters are given in Figs. 23 through 26 for $\phi = 0°$, 45°, 90° and -45°, respectively. The similar plots of CDC vs. Re are given in Figs. 27 through 30.

For given values of ϕ, Re and K, the values of CDC appear to be independent of the water depth, h. This is true for all other force coefficients. Ignoring the values of Re, the entire data of CDC are plotted versus K with ϕ as a parameter in Fig. 31. The curves in the figure show the approximate envelopes of the data for each ϕ values. The envelope values of CDC decrease slightly as K increases but are practically constant for larger values of K, say K >20.

The flange angle ϕ dramatically influences the value of CDC. The envelope values of CDC for K >20 are 1.0, 3.0 and 5.0 for ϕ = 0°, ±45° and 90°, respectively.

The CDC data with K >20 are plotted versus Re with ϕ as a parameter in Fig. 32. The solid line in the figure indicates the CDC data for a smooth circular cylinder near a plane boundary obtained from the wave force tests ($Re<10^5$) and the forced cylinder oscillation tests ($Re >10^5$) given in Ref. 5. The smooth cylinder value of CDC decreases gradually from 3.0 at $Re = 10^4$ to 0.8 at $Re = 3x10^5$ and then increases gradually to 1.1 at 10^6. For the range of Re covered, the split pipe data show the similar tendency as the smooth pipe. When the flanges of the split pipe are parallel to the flow (ϕ = 0°), the actual blockage area of split pipe is smaller than that of a circular cylinder with the same volume. As the flange angle ϕ to the flow increases, the blockage area increases and becomes larger than that of the equivalent circular cylinder. The drag force increases as the blockage area increases. This tendency is clearly indicated by the data.

7.4 Inertia Coefficient

The plots of CI+ vs. K and CI+ vs. Re for the four flange angles are given in Figs. 33 to 40. For ϕ = 0°, ±45°, the values of CI+ are nearly independent of K and Re. For ϕ = 90°, CI+ slightly increases as K and Re are increased. All of the CI+ data are plotted versus K in Fig. 41. The curves in the figure are the envelopes of the data. The value of CI+ increases significantly as the flange angle increases. This is also a blockage effect of the flanges.

The data of CI+ with K >20 are plotted versus Re in Fig. 42 and compared with the data for a smooth cylinder in Ref. 5. The comparison indicates that the split pipe with ϕ = 0° has about the same or slightly smaller values of CI+ as a smooth pipe, and that the CI+ value of the split pipe with ϕ = ±45° and 90° are larger than the smooth pipe values

Virtually no difference was found between CI+ and CI- values as shown in Tables 5 to 18.

7.5 Maximum Horizontal Force Coefficient

The complete plots of CHMAX vs. K and CHMAX vs. Re are given in Figs 43 to 50.

Ignoring the values of Re, all the CHMAX data are plotted versus K in Fig. 51. In the figure, the solid lines indicate the envelopes of the data for different ϕ values. The figure clearly shows that the maximum horizontal force on the split pipe drastically increases as the flange angle increases. The maximum horizontal forces for ϕ = 90° and ϕ = ±45° are respectively about three times and two times larger than that for ϕ = 0°. This is a very important factor to be aware of for design of split pipe.

7.6 Lift Coefficients

The upward and downward lift coefficients CL+ and CL- are plotted vs. K and Re for each of the four flange angles in Figs. 52 to 67.

Generally, the upward lift coefficient CL+ increases from zero to the maximum and then gradually decreases as K is increased. However, the downward lift coefficient CL- monotonously decreases as K is increased. This is because the wake formation is small and the flow is more of a potential flow

situation for a small value of K. The flow through the small clearance between the pipe and the floor induces a large downward lift force as theoretically shown in Ref. 9. For a large value of K, the nonsymmetric shape of the wake creates a large uplift as clearly pointed out in Ref. 4, 5 and 7.

For the case of $\phi = 0$, vertical vibrations of the split pipe were often observed when the waves became large or large values of Re and K. A few points with extraordinarily large values of CL+ in Figs. 52, 56, and 70 are due to vibration and should be ignored.

In Fig. 68, the values of CL+ for all four flange angles are plotted vs. K. The solid lines in the figure are the envelopes of the data. The uplift force is greatly influenced by the flange angle. The force increases accordingly in the order of $\phi = 0°$, 90°, -45° and 45°. The uplift force on the pipe at $\phi = 45°$ will be more than ten times as large as that at $\phi = 0°$. This is an important design factor to take into consideration.

The similar plots of CL- are given in Fig. 69. The downward lift force increases in the order of $\phi = 90°$, 0°, 45° and -45°. The downward lift forces have about the same magnitudes as the uplift forces. The lift force has at least twice the wave frequency. This may also be an important design factor to consider.

The lift force data for K >20 are compared with the data for a smooth circular cylinder in Figs. 70 and 71. Figure 70 indicates that the uplift force on the split pipe at $\phi = 90°$ is about as large as that on the equivalent circular pipe. The split pipe at $\phi = 0°$ has a slightly smaller value of CL+ than an equivalent circular pipe. The uplift coefficient for the split pipe at $\phi = 45°$ is about four times larger than that of a smooth pipe.

7.7 Effect of Flange Angle on Force Coefficients

In order to summarize the effect of the flange angle on the wave force coefficients of the split pipe, the envelope values of various force coefficients at K = 25 are plotted versus the flange angle ϕ in Fig. 72.

As can be seen, all of the wave forces are very strongly affected by the flange angle. All of the wave forces are minimum when the flange is parallel to the floor, $\phi = 0$. When the flange is perpendicular to the floor, $\phi = 90°$, the horizontal forces are maximum and more than five times as large as the forces for $\phi = 0°$; but the vertical forces are minimum. The vertical forces are maximum and as much as five times the vertical forces for $\phi = 0°$ when the flange angle is $\pm 45°$ to the floor.

8.0 ON THE APPLICATION OF THE PRESENT DATA

As demonstrated in Fig. 72, the single most important factor for the design of the split pipe is the flange angle. A slight misalignment of the flange from the horizontal position can increase the horizontal and vertical wave forces several times. Thus, very careful assessment must be made as to the range of the flange angle variation at the installation and the possible movements after the installation is in the field.

Once the design range of the flange angle is determined, the design wave forces may be determined as follows. The ranges of the Reynolds number, Re, and the Keulegan-Carpenter number, K, covered by the present tests are $10^4 < Re < 2 \times 10^5$ and $0 < K < 40$. Thus, if the design situations are within the range, the wave force coefficients determined from the tests can be directly used for design purposes. That is, if only the maximum horizontal and vertical forces are required for the design, they can be determined from the values of CHMAX, CL+ in Figs. 45 to 51 and 52 to 59 together with Eqs. 6 and 8. If the wave forces are required as functions of time, then the forces may be given by the Morrison equation, Eq. 1, and the drag and inertia coefficients determined from Figs. 23 to 32 and 33 to 42.

In most design wave situations, the Reynolds number Re becomes much larger. According to Ref. 5, the drag coefficient on a smooth pipe decreases from the subcritical value to a minimum value of 0.8 at about $Re = 3 \times 10^5$ and then seems to approach to a plateau value of 1.1 as Re is further increased as shown in Fig. 31. The split pipe data in Fig. 31 show the similar tendency for the Reynolds number covered. Thus, it may be reasonable to assume that the split pipe drag coefficients will also approach plateau values in the high Reynolds number range. Therefore, the drag coefficient given in Fig. 32

may be used for higher Reynolds number design situations. The same argument is true for the maximum force coefficients and the lift coefficient. Since the inertia forces are less important in the high Reynolds number design situations, the values given in Fig. 42 may be used.

9.0 SUMMARY AND CONCLUSIONS

The single most important design parameter for the wave force design of the split pipe is the flange angle ϕ, the orientation of the split pipe flanges to the flow direction. Both the horizontal force and the vertical force are minimum when the flanges are parallel to the bottom. The horizontal force increases 3 to 6 times as the flange angle ϕ increases from 0 to 90°. The vertical force increases up to 10 times as the flange angle varies from 0 to 45°. Thus, even a small misalignment of the flanges from the horizontal position can increase the wave forces several times and cause a pipe failure.

The drag, inertia and lift coefficients of the split pipe, obtained from the present tests, are correlated with the data of a smooth circular cylinder in Ref. 5. The trend of the data and the relative magnitudes of the force coefficients of the split pipe are found to be reasonable. This indicates the credibility of the data obtained.

The design criteria for the split pipe have been established which may be used even for the high Reynolds number design wave situations.

10.0 SUGGESTED FUTURE WORK

This work focused on determining design coefficients for split pipe for the specialized case of wave forces on the pipe with the wave crests parallel to the pipeline. The force coefficients were determined by assuming Airy wave theory and utilizing periodic waves for a variety of water depths. Actual design and construction conditions can be considerably different from these special cases. Therefore, in order to significantly add to design information, particularly the determining of hydrodynamic forces on split pipe under actual environmental conditions, the following suggestions are made for future work.

10.1 Predicted Water Velocities vs. Theory

The velocities of the horizontal motion of the water at the level of the pipe were measured during the work described herein and it is important that a comparison be made between the water velocities measured and those predicted by the Airy wave theory. During the testing, these data were recorded on 16-channel magnetic analog tape. This can be reproduced onto a visicorder paper trace recording or it can be digitized and processed digitally. Thus, the water motion at the pipe level experienced in the Wave Research Facility can be compared with predicted water motions in the ocean and an estimate can be made as to the validity of the Airy theory used and the resulting predictions of wave forces on split pipe.

10.2 Mean Square Error Method for Determining Coefficients

In another research project at OSU, the comparison of using the maximum value method for determining drag and added mass coefficients vs. using the

minimum mean square error method has been made at OSU. It was found that it is possible for the coefficients to be somewhat higher for the minimum mean square error method of evaluation rather than from the maximum value method. However, it is anticipated that less than a 10 to 20% difference will occur. This should be evaluated in order to determine if any change could be significant for design for split pipe in waves as utilized by the Navy. The computer program for determining the wave force coefficients by the least square method is available at Oregon State University but it will require some revisions for this work. This can be done with the data from the tests that are described in this report.

10.3 Skewed Waves

In nature the waves approach the pipelines in directions which are seldom such that the wave crests are parallel to the pipe alignment. More likely the waves will be oriented with the wave crest perpendicular to the pipe alignment or at some other angle of skewness. The effect of the skewness angle on such lift and drag coefficients should be investigated as a fairly high priority activity. Such tests are particularly difficult to perform and would probably have to be accomplished with long sections of pipe mounted differently than for this report and perhaps in a shoaling condition rather than for a horizontal bottom. Careful end conditions must be provided so that the leading end does not unnecessarily influence the data obtained. It is possible for a steady state uplift to occur from waves when the wave crests are perpendicular to the pipe center line.

10.4 Combined Effect of Current and Waves

It is particularly difficult to model current and waves superimposed in a laboratory. However, such a condition is common in nature. One possibility for investigating at least some aspects of this phenomenon and how it affects hydrodynamic loading is to tow a pipe section near the bottom into the waves and in the same direction as the waves to get an approximate idea of these combined forces. Powerful towing equipment does exist at OSU for towing such a pipe specimen. Thus, the combined effects of current and waves can be investigated at least approximately by towing the split pipe sections spanning the 12 foot width of the wave tank with waves.

10.5 Alternative Split Pipe With No Flanges

When the flanges of the split pipe are oriented at some angle to the incident flow, the wave forces can be increased up to six times, as found in this report. This may cause failures of pipe lines composed of split pipe. In order to eliminate this undesirable affect of split pipe flanges, a new design is suggested -- a split pipe without flanges. Given that the split pipe was purely cylindrical sections, much data already exist from various researchers as to the forces from waves and current. However, it is unlikely a new design will result in a purely cylindrical shape. Therefore, the shape will have some irregularities in order to accommodate a bolting arrangement. Any irregularity from the cylindrical shape will lekely influence the lift and drag coefficients for design purposes. Therefore, it would be very desirable to test such designs in the Wave Research Facility to obtain comparisons with the work accomplished in this report. Given that additional testing to determine the effects of skewness and the other items

which appear in this section on the standard split pipe with flanges, then it is likely that additional testing for other shapes will not need to be so comprehensive. Fewer tests may be needed in order to determine comparisons between other shapes and the split pipe flange sections as used herein.

10.6 Random Waves

The Wave Research Facility at OSU has a capability to produce wave spectra that closely approximate wave spectra in the ocean at a scale ratio of 1:10 or better. It would be useful to the Navy to investigate the influence on the hydrodynamic coefficients on split pipe due to irregular waves vs. periodic waves. This work can be done for various water depths as in this report.

11.0 REFERENCES

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Table 1 - TESTING SCHEDULE AND MODIFICATIONS

Day #	Date	Work (Scheduled)	Work (Done)
1	Mon., July 18, 1977	Floor construction	Floor construction
2	19	Test pipe installation	Floor construction
3	20	Test pipe installation	Test pipe installation
4	21	Calibration in air	Test pipe installation (east force dynamometer bent)
5	Fri., July 22, 1977	Calibration in water	Examination in air
6	Mon., July 25	Test series 9, series D	Calibration in water
7	26	8, dewater	Series 1, Series 2
8	27	4, series 5	series 3, watering, series 4
9	28	6, dewater	series 5, series 6, series 7
10	Fri., July 29	1, series 2	watering, series 8
11	Mon., Aug. 1	Test series 3, watering	Series 9, series 10, series 11
12	2	7, "	Series 12, dewatering, series 13
13	3	11, "	Dewatering, series 14
14	4	Calibration in water	Calibration in water
15	Fri., Aug. 5	Clean up	clean up

Table 2 - TEST COMBINATIONS (series number)

Wt. Depth / F. Angle	4 feet	6 feet	8 feet
0^o	1	6	9,11
45^o	2	5	10
90^o	3	4,7	8
-45^o	14	13	12

Table 3 - VALUES OF CLEAN MAXIMUM WAVE HEIGHTS (feet)

Water Depth \ Wave Period	2 sec	4 sec	6 sec
4 ft	1.7	2.1	2.1
6 ft	2.0	3.0	2.8
8 ft	1.9	4.0	3.3

Table 4 - Conversion Factors of Force Dynamometers

		a. Area ($\mu\varepsilon$ ft/lb)	b. Conversion factor (lb/$\mu\varepsilon$)	c. Calibration Pulse (lbs)
West Vertical	1	22.7	.410	--
	2	21.2	.441	--
	3	22.0	.426	34.4
West Horizontal	1	19.5	.478	--
	2	18.9	.493	--
	3	19.2	.486	39.2
East Vertical	1	21.1	.442	--
	2	18.6	.503	--
	3	19.9	.473	38.2
East Horizontal	1	20.7	.461	--
	2	20.3	.461	--
	3	20.5	.461	37.2

a. = Area below the influence curve

b. = 1/a = conversion of reading in $\mu\varepsilon$ to total force in lbs.

c. = Equivalent total force in lbs. of calibration pulse of 80.7 $\mu\varepsilon$

1. = before tests

2. = after tests

3. = average of 1 and 2

Table 5 - Wave Force Tests Data and Calculated Results for Series 1; h = 4 ft, $\phi = 0°$

* SERIES NO.1 , RUN 1-12 DATA 7/26/77 , 1103AM-0230PM PAGE 1

WATER DEPTH= 4.0FEET FLANGE ANGLE= 0.00DEGREE TOTAL VOLUME= 1.9017 FT3 LENGTH OF PIPE= 9.3331FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	RE**5	K
1	2.00	4.00	17.52	18.79	41.23	34.36	20.25	6.33	32.55	34.36	.599	.641	1.407	1.172	.691	.216	2.320	2.449	1.152	20.620
2	1.49	4.00	16.38	16.47	29.84	26.77	12.66	5.66	22.97	25.32	1.011	1.016	1.941	1.651	.781	.312	2.201	2.427	.856	15.333
3	.95	4.00	6.69	12.85	18.99	15.37	8.14	4.52	13.02	14.47	1.003	1.927	2.849	2.305	1.220	.678	1.346	2.162	.549	9.834
4	.63	4.00	0.00	3.29	9.04	8.69	1.45	1.45	8.69	8.69	0.000	1.149	7.152	3.026	.504	.504	1.978	1.978	.360	6.450
5	1.64	2.00	4.10	13.18	35.26	37.07	10.85	9.04	35.26	37.07	.469	1.481	3.962	4.165	1.219	1.016	2.781	2.398	.635	5.691
6	1.25	2.00	2.01	7.91	28.94	30.39	3.62	4.52	28.34	30.39	.388	1.528	5.591	5.871	.693	.974	2.454	2.577	.484	4.332
7	.85	2.00	1.5	5.77	17.18	23.87	0.00	0.00	17.18	23.87	.628	2.407	7.173	9.966	0.000	0.000	2.142	2.976	.329	2.947
8	.55	2.00	0.00	1.32	9.40	11.39	0.00	0.00	11.39	9.40	0.000	1.253	8.941	10.833	0.000	0.000	2.143	1.769	.218	1.953
9	2.03	6.00	10.03	6.59	24.41	40.59	10.85	43.40	18.08	37.98	.295	.194	.717	1.196	.319	1.276	1.794	3.768	1.241	33.323
10	1.30	6.00	10.36	17.46	15.91	33.64	8.59	18.09	10.85	23.51	.740	1.247	1.137	2.403	.607	1.356	1.579	3.637	.796	21.374
11	.79	6.00	10.03	9.55	8.68	17.72	6.33	11.39	5.79	11.75	1.949	1.857	1.687	3.444	1.230	2.214	1.477	2.999	.483	12.959
12	.46	6.00	.67	2.64	5.43	3.07	2.35	1.27	4.52	3.07	.380	1.500	3.037	1.749	1.339	.720	1.374	1.342	.282	7.573

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	WL-FT
1	2.56	4.01	47.39	31.13	73.57	63.35	18.39	6.30	29.76	31.67	1.617	1.062	2.510	2.161	.627	.215	2.121	2.257	43.049
2	1.90	2.99	44.84	30.03	52.83	48.70	10.47	5.11	21.74	22.99	2.766	1.853	3.260	3.005	.670	.315	2.083	2.203	43.049
3	1.22	1.91	23.73	24.17	31.77	32.36	5.85	5.11	11.70	15.33	3.554	3.625	4.764	4.853	.879	.766	1.749	2.290	43.049
4	.90	1.26	0.00	7.69	16.39	16.35	.84	1.02	7.69	7.66	0.000	2.681	5.712	5.699	.291	.356	1.752	1.746	43.049
5	1.41	4.42	11.33	26.37	66.21	71.52	5.95	8.51	33.10	35.76	1.270	2.963	7.439	8.036	.657	.357	2.141	2.313	19.087
6	1.07	3.37	5.83	15.39	50.83	57.90	3.34	4.26	25.41	28.95	1.127	2.972	9.922	11.188	.645	.323	2.155	2.455	19.087
7	.73	2.29	5.47	7.32	36.78	42.57	0.00	0.00	18.39	21.29	2.283	3.058	15.357	17.774	0.000	0.000	2.293	2.654	19.087
8	.49	1.52	2.13	3.06	20.06	20.44	0.00	0.00	9.70	10.22	2.090	3.492	19.076	19.431	0.000	0.000	1.826	1.922	19.087
9	2.75	2.88	37.18	15.38	45.14	73.73	8.69	37.46	15.98	35.76	1.093	.452	1.327	2.152	.256	1.101	1.576	3.548	66.517
10	1.77	1.85	26.25	45.05	26.75	60.62	7.52	17.03	8.36	23.84	1.875	3.218	1.911	4.331	.537	1.216	1.293	3.688	66.517
11	1.07	1.12	23.76	16.48	14.04	30.65	5.02	10.22	5.12	10.22	4.605	3.203	2.729	5.957	.975	1.996	1.280	2.607	66.517
12	.63	.66	1.04	6.96	7.36	6.81	1.51	1.70	3.34	3.41	.622	3.959	4.186	3.876	.855	.969	1.460	1.487	66.517

Table 6 - Wave Force Tests Data and Calculated Results for Series 2; h = 4 ft, $\phi = 45^o$

* SERIES NO.2 , RUN 13-24 DATA 7/26/77 , 0355PM-0940AM (7/27/77) PAGE 2

WATER DEPTH= 4.0FEET FLANGE ANGLE= 45.0DEGREES TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	RE**5	K
13	1.64	2.00	25.91	40.36	45.21	42.96	24.41	21.70	40.69	42.50	2.911	4.535	5.080	4.815	2.743	2.438	2.531	2.748	.635	5.681
15	.84	2.00	3.84	11.37	22.61	23.51	4.52	3.62	22.61	23.51	1.644	4.862	9.670	10.056	1.934	1.547	2.452	2.967	.325	2.912
16	.59	2.00	.84	2.97	11.21	12.12	1.81	1.81	11.21	12.12	.727	2.580	9.754	10.540	1.573	1.573	2.018	2.180	.228	2.042
17	1.11	4.00	109.31	52.72	55.10	36.17	51.72	8.32	41.59	30.74	12.157	5.862	7.240	4.022	5.752	.925	5.352	3.956	.638	11.420
17	1.95	4.00	108.98	54.36	65.10	37.43	45.57	9.04	43.95	29.48	3.916	1.953	2.339	1.345	1.638	.325	3.214	2.156	1.122	20.091
18	1.35	4.00	64.52	32.95	43.76	21.70	27.95	7.23	32.55	21.70	4.803	2.453	3.258	1.616	2.073	.539	3.427	2.285	.780	13.958
19	.94	4.00	22.56	24.71	27.49	18.99	7.79	7.23	18.63	18.99	3.459	3.787	4.213	2.910	1.192	1.109	2.814	2.868	.543	9.728
20	.54	4.00	6.35	7.91	13.02	8.14	4.52	1.81	13.02	8.14	2.933	3.651	6.013	3.758	2.088	.835	3.414	2.134	.313	5.604
21	2.03	6.00	133.72	19.77	86.81	19.89	79.33	19.89	53.17	19.89	3.930	.581	2.551	.585	2.349	.585	5.276	1.974	1.241	33.323
22	1.33	6.00	71.20	14.83	51.36	16.28	35.45	14.47	30.74	7.96	4.854	1.011	3.501	1.110	2.417	.986	4.646	1.203	.815	21.879
23	.77	6.00	31.42	9.89	25.32	7.23	16.10	5.61	15.19	4.52	6.436	2.025	5.196	1.482	3.297	1.148	3.379	1.184	.470	12.622
24	.46	6.00	4.68	4.45	6.87	5.06	3.62	2.71	6.87	5.06	2.663	2.531	3.910	2.881	2.058	1.543	3.000	2.211	.282	7.573

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	WL-FT
13	1.41	4.42	53.59	90.57	77.58	81.74	20.40	22.99	35.95	40.87	6.021	9.052	8.716	9.184	2.292	2.583	2.325	2.643	18.087
15	.72	2.27	9.11	22.71	39.79	47.00	3.34	3.41	19.90	23.50	3.898	9.713	17.021	20.104	1.430	1.457	2.511	2.965	18.087
16	.51	1.59	0.00	3.06	20.40	21.12	1.67	1.70	10.20	10.56	0.000	3.186	17.745	18.364	1.454	1.481	1.935	1.900	18.087
17	1.42	2.22	212.89	91.56	115.70	76.29	46.91	11.92	35.11	30.65	23.675	10.182	12.867	8.484	5.206	1.325	4.518	3.944	43.049
17	2.49	3.91	216.90	102.55	134.06	71.52	38.79	10.22	39.63	29.44	7.794	3.685	12.003	2.570	1.394	.367	2.898	2.090	43.049
18	1.73	2.72	123.94	56.40	74.90	53.13	22.40	9.86	26.75	26.22	9.227	4.199	5.576	3.955	1.668	.659	2.416	2.761	43.049
19	1.21	1.89	47.39	41.02	50.49	36.10	6.19	6.81	16.93	19.07	7.263	6.296	7.738	5.533	.949	1.044	2.551	2.891	43.049
20	.69	1.09	14.59	15.79	21.74	17.71	3.34	3.41	6.69	7.32	6.733	7.272	10.037	8.179	1.544	1.573	1.754	1.920	43.049
21	2.75	2.88	253.72	43.97	160.51	35.42	65.49	17.71	51.16	17.71	7.456	1.292	4.717	1.041	1.936	.520	5.077	1.757	66.517
22	1.81	1.89	139.94	21.24	93.63	29.29	31.43	12.60	28.76	6.13	9.543	1.448	6.383	1.997	3.143	.959	4.346	.926	66.517
23	1.04	1.09	65.52	17.54	45.14	12.34	14.34	4.94	14.38	3.75	13.440	3.601	3.247	2.651	2.877	1.012	3.767	.941	66.517
24	.63	.66	10.21	9.15	13.39	7.93	3.31	1.87	4.69	4.26	5.907	5.264	7.610	4.457	1.712	1.066	2.344	1.859	66.517

Table 7 - Wave Force Tests Data and Calculated Results for Series 3; h = 4 ft, $\phi = 90^0$

* SERIES NO.3 , RUN 25-36 DATA 7/27/77 , 1050AM-1145AM

WATER DEPTH= 4.0FEET FLANGE ANGLE= 90.0DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	RE**5	K
25	1.64	2.00	28.42	29.65	74.15	65.10	0.00	0.00	61.49	54.25	3.192	3.331	8.330	7.314	0.000	0.000	3.476	3.509	.635	5.691
26	1.38	2.00	20.06	23.06	52.45	47.92	25.32	19.89	48.83	39.79	3.414	3.925	8.926	8.156	4.309	3.386	3.886	3.167	.516	4.616
27	.92	2.00	6.85	11.53	30.74	30.39	12.12	11.03	26.22	28.94	2.433	4.09	10.917	10.784	4.302	3.917	3.015	3.327	.357	3.196
28	.59	2.00	1.00	2.90	13.02	14.83	1.91	2.71	13.02	14.83	.872	2.436	11.327	12.900	1.573	2.360	2.343	2.669	.228	2.042
29	2.13	4.00	56.83	5.59	169.27	65.10	121.17	37.25	57.97	36.89	1.704	.198	5.075	1.952	3.633	1.117	3.867	2.465	1.229	21.994
30	.92	4.00	18.05	0.00	45.21	21.34	34.00	6.51	19.17	14.83	2.891	0.000	7.240	3.417	5.445	1.043	2.960	2.290	.532	9.517
31	1.00	4.00	18.39	6.26	53.35	26.58	29.49	6.69	25.68	17.54	2.483	.845	7.205	3.591	3.981	.904	3.642	2.488	.579	10.363
32	1.44	4.00	7.19	6.10	19.89	13.93	10.13	5.43	14.11	12.66	.476	.403	1.317	.922	.670	.359	1.400	1.257	.827	14.904
33	2.10	6.00	51.82	3.29	195.31	37.62	144.68	29.94	61.49	25.32	1.421	.096	5.355	1.031	3.966	.793	5.893	2.426	1.285	34.501
34	1.35	6.00	35.10	4.94	116.46	28.94	86.81	28.94	30.74	19.89	2.321	.327	7.701	1.913	5.740	1.913	4.576	2.961	.827	22.215
35	.92	6.00	11.20	4.61	52.99	17.18	40.69	14.47	15.37	17.18	2.016	.830	9.539	3.093	7.325	2.605	3.775	4.219	.501	13.464
36	.95	6.00	10.70	5.60	24.23	15.19	17.00	10.13	10.85	15.19	1.425	.746	3.228	2.024	2.265	1.349	2.292	3.209	.583	15.652

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	WL-FT
25	1.41	4.42	54.59	65.92	140.44	122.61	0.00	0.00	56.85	49.38	6.143	7.407	15.779	13.775	0.000	0.000	3.676	3.194	18.087
26	1.14	3.59	36.45	50.54	96.97	90.25	20.06	17.03	42.63	37.46	6.204	8.602	16.504	15.369	3.415	2.899	3.393	2.982	18.087
27	.79	2.49	13.85	28.57	60.19	59.60	9.20	8.17	28.42	28.19	4.919	10.144	21.373	21.164	3.265	2.902	3.268	3.230	18.087
28	.51	1.59	2.59	6.59	25.08	27.25	1.67	3.41	12.54	13.62	2.220	5.735	21.817	23.702	1.454	2.963	2.257	2.452	18.087
29	2.73	4.28	102.90	9.52	264.17	130.78	110.35	41.89	55.17	35.08	3.082	.285	7.920	3.921	3.309	1.256	3.686	2.344	43.049
30	1.19	1.85	30.39	2.93	93.60	47.69	29.76	7.06	16.39	16.19	4.962	.469	13.347	7.635	4.766	1.227	2.530	2.498	43.049
31	1.28	2.62	32.91	13.92	94.30	57.90	23.91	9.88	20.57	20.26	4.431	1.880	12.736	7.820	3.223	1.334	2.916	2.874	43.049
32	1.83	2.88	14.58	14.65	35.11	27.25	8.19	5.62	12.04	13.29	.965	.970	2.324	1.803	.542	.372	1.195	1.319	43.049
33	2.85	2.97	80.20	25.64	93.63	20.44	131.75	27.25	55.51	23.84	2.199	.703	2.567	.560	3.612	.747	5.120	2.285	66.517
34	1.84	1.92	51.04	16.11	230.73	51.39	41.93	25.54	31.77	15.33	3.375	1.066	15.257	3.379	5.417	1.689	4.728	2.281	66.517
35	1.11	1.16	23.70	7.32	104.33	27.33	36.29	12.77	15.05	13.36	4.266	1.319	18.782	5.029	6.532	2.299	3.695	3.429	66.517
36	1.29	1.35	18.23	18.31	53.50	21.90	16.05	6.81	12.37	10.90	2.429	2.439	7.127	2.304	2.138	.907	2.614	2.302	66.517

Table 8 - Wave Force Tests Data and Calculated Results for Series 4; h = 6 ft, ϕ = 90^0

* SERIES NO.4 , RUN 37-48 DATA 7/27/77 , 030.PM-0400PM

WATER DEPTH= 6.0FEET FLANGE ANGLE= 90.0DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	RE**5	K
37	1.95	2.00	14.21	19.44	38.88	39.42	19.83	19.35	34.90	33.46	3.599	4.924	9.848	9.985	5.039	4.901	3.389	3.249	.423	3.784
38	1.51	2.00	7.52	9.39	29.84	28.21	11.75	6.69	25.32	25.32	3.183	3.973	12.626	11.937	4.974	2.831	3.177	3.177	.327	2.927
39	1.05	2.00	1.34	4.61	21.16	16.64	6.33	4.52	18.08	16.64	1.175	4.054	19.595	14.622	5.563	3.973	3.271	3.009	.227	2.031
40	.69	2.00	.94	1.99	7.41	10.85	.93	.90	7.41	10.85	1.754	4.149	15.564	22.776	1.899	1.899	2.073	3.033	.147	1.314
41	2.92	4.00	55.99	6.32	162.76	83.19	126.59	28.94	79.57	37.62	1.516	.187	4.407	2.252	3.427	.783	5.052	2.388	1.293	23.145
42	2.07	4.00	38.11	3.29	97.66	66.55	70.89	27.49	38.34	34.72	2.054	.178	5.263	3.587	3.821	1.481	3.434	3.110	.916	16.405
43	1.25	4.00	13.37	4.94	54.99	40.15	30.74	19.45	24.23	22.42	1.976	.730	8.123	5.932	4.542	2.725	3.594	3.326	.553	9.908
44	.63	4.00	7.86	4.78	17.18	16.28	6.15	3.62	12.66	12.66	4.643	2.823	10.154	9.619	3.634	2.138	3.755	3.755	.277	4.954
45	2.77	6.00	41.79	2.14	173.61	36.17	137.44	20.98	52.81	21.70	1.041	.053	4.327	.901	3.425	.523	4.925	1.983	1.348	36.186
46	1.85	6.00	35.10	2.97	108.51	34.72	81.02	12.30	39.79	11.57	1.968	.166	6.085	1.947	4.543	.690	5.453	1.586	.898	24.124
47	1.13	6.00	13.71	2.97	50.64	26.40	36.17	14.47	14.47	10.85	2.058	.445	7.603	3.965	5.431	2.172	3.245	2.434	.549	14.742
48	.67	6.00	3.01	3.79	12.66	9.04	5.43	3.07	6.33	6.69	1.294	1.629	5.444	3.888	2.333	1.322	2.402	2.540	.324	8.711

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	WL-FT
37	.94	2.95	25.52	42.85	75.91	74.93	17.83	16.18	33.77	31.50	6.463	10.853	19.226	18.978	4.531	4.099	3.279	3.059	19.623
38	.73	2.29	11.67	22.71	54.17	55.17	10.03	5.11	25.08	24.69	4.936	9.608	22.922	23.346	4.245	2.162	3.148	3.899	19.623
39	.50	1.58	1.92	10.99	34.44	35.76	4.13	5.11	15.88	17.88	1.602	9.656	30.269	31.429	3.673	4.490	2.873	3.234	19.623
40	.33	1.02	0.00	3.65	16.72	15.33	.84	.85	8.36	7.66	0.000	7.688	35.035	32.171	1.755	1.787	2.337	2.142	19.623
41	2.07	4.51	137.05	19.69	77.95	36.38	120.33	30.65	73.57	37.46	3.711	.531	2.110	.985	3.259	.830	4.671	2.379	51.295
42	2.03	3.19	90.69	10.29	45.75	31.19	62.97	26.57	34.78	34.74	4.889	.555	2.466	1.681	3.388	1.432	3.115	3.112	51.295
43	1.23	1.93	14.40	3.30	102.99	73.57	24.42	14.73	19.73	19.75	2.129	.487	15.217	10.970	4.200	2.769	2.926	2.930	51.295
44	.61	.96	13.45	11.35	30.43	33.33	5.02	3.41	11.37	11.92	8.187	6.710	17.994	19.726	2.964	2.013	3.373	3.536	51.295
45	2.99	3.13	95.73	75.97	94.73	16.24	122.30	20.44	52.17	25.88	2.346	1.893	2.112	.405	3.050	.509	4.767	2.365	80.515
46	1.99	2.09	84.65	49.99	51.8.	45.49	74.30	12.94	37.45	10.90	4.747	2.803	2.904	2.550	4.203	.726	5.133	1.496	80.515
47	1.22	1.29	14.40	7.87	80.28	42.23	33.44	13.62	14.38	10.90	2.162	1.182	13.255	6.341	5.021	2.346	3.225	2.444	80.515
48	.72	.75	7.29	4.79	25.69	19.73	5.02	3.41	5.95	5.96	3.135	1.890	10.785	8.055	2.157	1.465	2.221	2.262	80.515

Table 9 - Wave Force Tests Data and Calculated Results for Series 5; h = 6 ft, $\phi = 45^0$

* SERIES NO.5, RUN 49-60 DATA 7/28/77 , 1000AM-1200PM

WATER DEPTH= 6.0FEET FLANGE ANGLE= 45.00DEGREE TOTAL VOLUME= 1.9017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	COC	COT	CI+	CI-	RE**5	K
49	1.99	2.00	10.96	16.47	28.03	29.33	12.12	4.16	25.86	25.32	2.667	4.044	6.881	6.981	2.974	1.021	2.472	2.420	.429	3.843
50	1.54	2.00	3.34	10.38	20.80	23.51	5.43	3.26	19.89	21.70	1.358	4.218	8.451	9.554	2.205	1.323	2.447	2.669	.334	2.987
51	1.04	2.00	2.17	4.45	14.47	16.28	2.17	3.62	14.47	16.28	1.948	3.987	12.958	14.589	1.945	3.242	2.543	2.973	.225	2.011
52	.69	2.00	1.17	2.14	6.33	7.60	.90	.90	6.33	7.60	2.348	4.298	12.702	15.243	1.815	1.815	1.730	2.076	.150	1.344
53	2.97	4.00	143.75	54.03	101.27	60.76	79.57	18.08	47.02	28.94	3.759	1.413	2.648	1.589	2.081	.473	2.934	1.806	1.316	23.551
54	2.05	4.00	83.57	52.72	54.25	47.02	41.59	7.23	32.55	23.51	4.595	2.898	2.983	2.585	2.287	.398	2.945	2.127	.907	16.242
55	1.25	4.00	33.93	30.48	29.84	21.70	15.73	7.23	19.99	19.89	5.013	4.503	4.409	3.206	2.325	1.069	2.951	2.951	.553	9.908
56	.77	4.00	7.86	12.03	12.12	9.95	4.52	3.62	9.95	9.95	3.071	4.702	4.737	3.889	1.768	1.414	2.400	2.400	.340	6.091
57	2.79	6.00	138.06	16.47	114.29	25.32	108.51	14.47	43.40	16.64	3.390	.405	2.807	.622	2.665	.355	3.937	1.509	1.358	36.454
58	1.85	6.00	82.74	16.47	56.79	22.42	56.79	10.85	25.32	9.04	4.640	.924	3.184	1.257	3.184	.608	3.470	1.239	.898	24.124
59	1.09	6.00	41.12	15.65	23.87	14.83	18.08	6.33	13.56	6.69	6.776	2.579	3.934	2.444	2.980	1.043	3.187	1.572	.524	14.072
60	.64	6.00	7.52	6.59	8.68	5.06	3.07	3.62	4.52	5.06	3.499	3.065	4.037	2.355	1.430	1.682	1.785	1.999	.312	8.376

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	COC	COT	CI+	CI-	WL-FT
49	.95	2.99	23.70	37.36	55.17	58.58	10.87	3.92	26.75	26.40	5.816	9.170	13.544	14.380	2.669	.961	2.557	2.523	19.623
50	.74	2.33	6.56	24.99	40.80	44.96	5.02	3.41	18.39	21.29	2.667	10.121	16.578	18.269	2.039	1.384	2.262	2.618	19.623
51	.50	1.57	2.55	8.05	28.42	29.97	2.84	2.55	13.71	14.99	2.287	7.222	25.477	26.864	2.549	2.290	2.504	2.737	19.623
52	.33	1.05	0.00	3.66	13.39	14.65	.84	.85	6.69	7.32	0.000	7.350	26.842	29.390	1.678	1.709	1.828	2.001	19.623
53	2.92	4.59	66.35	32.96	96.97	61.31	78.92	20.44	46.91	35.42	1.735	.862	2.536	1.603	2.064	.534	2.921	2.210	51.295
54	2.01	3.16	134.98	106.21	113.69	102.18	41.87	8.51	31.77	23.94	7.415	5.839	6.251	5.617	2.299	.469	2.974	2.157	51.295
55	1.23	1.93	69.26	59.33	60.19	54.49	15.05	6.81	18.39	18.73	10.234	8.766	8.893	8.052	2.223	1.006	2.728	2.778	51.295
56	.75	1.19	14.53	26.37	20.06	22.14	3.34	4.26	8.36	10.22	5.701	10.309	7.844	8.655	1.307	1.664	2.017	2.465	51.295
57	3.01	3.15	295.28	90.10	58.52	11.32	130.32	13.62	40.13	15.67	7.251	2.213	1.437	.293	2.464	.335	3.640	1.421	80.515
58	1.99	2.09	89.31	30.21	60.19	27.25	30.10	5.81	10.03	5.79	5.008	1.694	3.375	1.529	1.689	.382	1.375	.794	80.515
59	1.16	1.22	81.29	42.12	51.83	27.75	20.06	5.45	13.04	5.96	13.395	6.941	8.541	4.490	3.306	.899	3.064	1.400	80.515
60	.63	.72	13.85	14.65	15.05	10.22	2.84	3.41	4.35	5.11	6.443	6.814	6.939	4.752	1.322	1.584	1.716	2.017	80.515

Table 10 - Wave Force Tests Data and Calculated Results for Series 6; h = 6 ft, $\phi = 0^0$

* SERIES NO.6 , RUN 61-72 DATA 7/29/77 , 0145PM-0300PM

WATER DEPTH= 6.0FEET FLANGE ANGLE= 0.0DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	COC	COT	CI+	CI-	RE**5	K
61	1.95	2.00	0.00	5.77	22.61	26.22	4.52	3.62	22.61	26.22	0.000	1.460	5.726	6.642	1.145	.916	2.195	2.546	.423	3.784
62	1.49	2.00	.84	3.62	18.99	20.80	1.81	1.81	18.99	20.80	.363	1.576	8.258	9.044	.786	.786	2.416	2.646	.323	2.848
63	1.03	2.00	0.00	1.98	13.56	13.56	0.00	0.00	13.56	13.56	0.000	1.808	12.402	12.402	0.000	0.000	2.502	2.502	.222	1.991
64	.41	2.00	0.00	1.65	6.51	7.23	0.00	0.00	6.51	7.23	0.000	9.414	37.205	41.339	0.000	0.000	3.003	3.336	.089	.797
65	2.97	4.00	30.92	18.12	45.21	32.55	25.32	7.23	34.36	32.55	.809	.474	1.182	.851	.662	.189	2.144	2.031	1.316	23.551
66	2.05	4.00	24.24	16.47	32.55	26.22	11.75	7.23	25.32	26.22	1.332	.906	1.790	1.442	.646	.398	2.291	2.373	.907	16.242
67	1.25	4.00	11.37	14.83	19.08	17.54	7.79	3.62	16.28	17.18	1.679	2.191	2.672	2.592	1.149	.534	2.414	2.548	.553	9.908
68	.77	4.00	.84	3.29	8.32	8.32	1.81	0.00	8.32	8.32	.327	1.288	3.252	3.252	.707	0.000	2.007	2.007	.340	6.091
69	2.72	6.00	23.40	9.23	45.21	20.98	32.55	7.23	27.13	16.28	.605	.239	1.170	.543	.842	.187	2.525	1.515	1.323	35.516
70	1.79	6.00	15.88	6.92	29.84	12.30	18.99	3.62	18.09	8.50	.942	.410	1.770	.730	1.127	.215	2.550	1.198	.873	23.454
71	1.13	6.00	12.54	7.58	14.47	8.68	7.23	3.62	10.85	6.33	1.882	1.138	2.172	1.303	1.086	.543	2.434	1.420	.549	14.742
72	.53	6.00	3.61	3.29	4.52	4.52	1.81	1.81	3.62	4.52	2.022	2.214	3.038	3.038	1.215	1.215	1.716	2.145	.260	6.969

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	COC	COT	CI+	CI-	WL-FT
61	.94	2.95	6.20	10.99	45.14	51.99	2.51	3.41	22.57	25.54	1.570	2.783	11.434	12.940	.635	.863	2.192	2.480	19.623
62	.72	2.25	5.47	7.32	33.44	39.17	1.67	1.70	16.72	19.58	2.378	3.185	14.542	17.033	.727	.741	2.127	2.492	19.623
63	.49	1.55	1.82	7.32	22.74	26.57	0.00	0.00	11.37	13.29	1.667	6.697	20.791	24.290	0.000	0.000	2.098	2.451	19.623
64	.20	.62	0.00	3.66	10.03	13.62	0.00	0.00	5.02	6.81	0.000	20.930	57.328	77.853	0.000	0.000	2.313	3.142	19.623
65	2.92	4.59	58.33	76.18	93.60	57.90	23.41	6.81	30.93	28.95	1.525	1.992	2.186	1.514	.612	.178	1.930	1.806	51.295
66	2.01	3.16	41.92	54.20	55.51	50.41	10.03	5.11	23.41	25.20	2.305	2.980	3.052	2.771	.552	.281	2.118	2.280	51.295
67	1.23	1.93	25.52	29.30	33.44	32.36	5.45	3.41	15.05	16.19	3.770	4.329	4.941	4.781	.863	.503	2.232	2.400	51.295
68	.75	1.19	3.65	5.86	14.38	14.30	0.00	0.00	7.19	7.15	1.425	2.291	5.622	5.592	0.000	0.000	1.735	1.726	51.295
69	2.93	3.07	51.04	54.94	83.60	35.42	31.10	6.81	26.75	14.30	1.320	1.421	2.163	.916	.805	.176	2.491	1.332	80.515
70	1.94	2.03	40.10	42.12	51.83	23.94	15.89	1.70	18.39	6.81	2.379	2.499	3.075	1.414	.942	.101	2.593	.960	80.515
71	1.22	1.29	25.52	36.62	26.75	14.39	6.69	2.21	10.33	5.96	3.832	5.499	4.017	2.149	1.004	.332	2.250	1.337	80.515
72	.59	.60	6.56	6.53	10.03	6.81	1.67	1.19	4.19	3.41	4.403	4.429	6.740	4.577	1.123	.401	1.983	1.616	80.515

Table 11 - Wave Force Tests Data and Calculated Results for Series 7; h = 6 ft, $\phi = 90^0$

* SERIES 107 , RUN 73-84 DATA 7/28/77 , 0400PM-0500PM

WATER DEPTH= 6.0FEET FLANGE ANGLE= 90.00DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	CDC	CDT	CI+	CI-	RE**5	K
73	1.95	2.00	16.55	18.45	42.50	40.69	18.99	14.47	36.17	35.26	4.191	4.673	10.764	10.306	4.809	3.664	3.512	3.424	.423	3.784
74	1.97	2.00	8.36	11.20	30.74	28.94	11.75	10.65	25.32	27.13	2.073	2.778	7.625	7.177	2.915	2.691	2.433	2.607	.427	3.823
75	1.05	2.00	2.01	4.94	19.89	18.27	7.23	5.06	18.08	18.27	1.763	4.343	17.483	16.052	6.357	4.450	3.271	3.304	.227	2.031
76	.66	2.00	0.00	1.65	9.04	9.22	1.81	1.81	9.04	9.22	0.000	3.677	20.185	20.589	4.037	4.037	2.607	2.659	.142	1.274
77	2.87	4.00	51.82	4.94	162.76	75.95	126.59	36.17	65.10	43.40	1.453	.139	4.565	2.131	3.551	1.015	4.207	2.805	1.270	22.739
78	2.10	4.00	33.93	2.47	101.27	68.72	65.10	21.70	42.68	34.35	1.776	.129	5.300	3.596	3.407	1.136	3.767	3.033	.930	16.648
79	1.26	4.00	18.39	2.47	49.73	41.05	25.32	15.37	23.51	23.51	2.673	.359	7.229	5.967	3.680	2.234	3.459	3.459	.558	9.989
80	.77	4.00	5.01	5.77	17.19	16.92	5.43	4.52	9.04	12.66	1.960	2.254	6.717	6.575	2.121	1.768	2.182	3.054	.340	6.091
81	2.87	6.00	40.12	0.00	177.23	46.30	133.83	17.36	47.02	18.08	.930	0.000	4.107	1.073	3.101	.402	4.143	1.593	1.397	37.526
82	1.85	6.00	26.74	4.94	104.89	36.17	79.57	21.70	28.94	14.47	1.500	.277	5.992	2.028	4.462	1.217	3.366	1.983	.898	24.124
83	1.13	6.00	13.71	1.99	50.64	25.32	36.17	16.28	18.08	18.08	2.058	.297	7.603	3.802	5.431	2.444	4.056	4.056	.549	14.742
84	.66	6.00	4.18	1.99	15.37	9.40	4.52	3.62	5.43	7.23	1.854	.877	6.818	4.171	2.005	1.604	2.091	2.769	.319	8.577

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	CDC	CDT	CI+	CI-	WL-FT
73	.94	2.95	27.34	44.59	78.59	78.33	16.72	11.07	33.44	35.76	6.925	11.317	13.903	19.841	4.235	2.804	3.247	3.472	19.623
74	.95	2.94	14.22	26.37	59.52	57.22	10.53	11.07	25.08	25.54	3.526	6.540	14.514	14.192	2.613	2.745	2.410	2.454	19.623
75	.50	1.58	2.19	14.65	36.78	37.46	5.85	5.45	15.68	17.89	1.922	12.875	32.326	32.925	5.143	4.799	2.873	3.234	19.623
76	.32	.99	0.00	4.39	16.72	17.71	1.67	1.70	8.36	8.86	0.000	9.811	37.323	39.535	3.732	3.801	2.410	2.553	19.623
77	2.82	4.43	105.81	19.32	90.78	37.67	108.34	40.87	60.19	40.87	2.968	.514	2.266	1.057	3.039	1.146	3.890	2.641	51.295
78	2.06	3.24	24.61	3.85	137.29	114.44	53.50	22.82	36.79	34.06	1.288	.201	13.324	5.989	2.800	1.194	3.247	3.806	51.295
79	1.24	1.94	33.54	8.42	98.65	73.23	23.41	17.03	20.06	22.14	4.875	1.224	14.339	10.644	3.402	2.475	2.952	3.257	51.295
80	.75	1.19	13.49	10.99	30.10	34.06	4.14	3.41	8.36	13.62	5.273	4.296	11.766	13.315	1.634	1.332	2.317	3.297	51.295
81	3.10	3.25	15.68	14.65	167.20	42.23	117.04	20.44	46.81	20.44	.363	.339	3.875	.979	2.712	.474	4.125	1.801	80.515
82	1.99	2.09	52.90	40.31	50.92	17.12	66.99	17.03	20.75	13.62	2.967	2.260	2.856	.960	3.750	.355	3.667	1.857	80.515
83	1.22	1.28	12.21	11.99	30.29	46.32	33.44	17.03	16.72	17.03	1.834	1.787	13.557	6.355	5.021	2.557	3.750	3.819	80.515
84	.71	.74	7.24	4.39	25.03	19.75	4.19	3.41	5.02	6.81	3.234	1.949	11.124	8.767	1.854	1.511	1.934	2.626	80.515

Table 12 - Wave Force Tests Data and Calculated REsults for Series 8; h = 8 ft, $\phi = 90^0$

* SERIES NO.8 , RUN 85-96 DATA 7/29/77 , 100JAN- . PAGE 8

WATER DEPTH= 8.0FEET FLANGE ANGLE= 90.00DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	CDC	CDT	CI+	CI-	RE**5	K
85	1.85	2.00	1.67	6.25	18.99	19.89	4.52	4.16	18.99	19.89	1.514	5.670	17.198	18.017	4.095	3.767	3.487	3.653	.224	2.001
86	1.44	2.00	.84	3.62	13.56	16.28	1.81	1.81	13.56	16.28	1.251	5.426	20.307	24.369	2.709	2.708	3.202	3.842	.174	1.556
87	1.03	2.00	0.00	1.98	8.86	10.67	0.00	0.00	8.96	10.67	0.000	5.801	26.004	31.310	0.000	0.000	2.929	3.526	.124	1.112
88	.62	2.00	0.00	1.49	4.52	4.52	0.00	0.00	4.52	4.52	0.000	12.085	36.853	36.853	0.000	0.000	2.490	2.490	.075	.667
89	4.02	4.00	45.13	8.24	188.08	112.12	115.74	65.10	86.81	54.25	.979	.179	4.082	2.433	2.512	1.413	4.935	3.084	1.444	25.851
90	2.97	4.00	33.43	6.59	115.74	75.95	61.49	50.64	50.64	36.17	1.326	.261	4.590	3.012	2.439	2.008	3.891	2.779	1.068	19.125
91	1.95	4.00	20.89	1.65	61.49	48.93	32.55	34.36	28.94	27.13	1.930	.152	5.680	4.511	3.007	3.174	3.394	3.182	.700	12.530
93	3.23	6.00	29.42	8.24	173.61	52.08	101.27	28.94	57.87	21.70	.756	.212	4.459	1.338	2.601	.743	5.368	2.013	1.327	35.645
94	2.31	6.00	15.04	3.29	99.83	42.69	68.72	18.08	47.02	10.85	.757	.166	5.025	2.148	3.459	.910	6.106	1.409	.948	25.461
95	1.35	6.00	10.03	1.99	43.40	29.65	25.32	12.66	14.47	10.85	1.467	.289	6.348	4.338	3.703	1.852	3.203	2.402	.556	14.937
96	.70	6.00	4.18	1.90	12.66	10.95	5.43	5.43	5.43	7.23	2.303	1.090	6.977	5.980	2.990	2.990	2.331	3.188	.287	7.695

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	CDC	CDT	CI+	CI-	WL-FT
85	.50	1.56	3.65	11.72	35.11	37.46	3.85	4.26	17.56	18.73	3.302	10.615	31.800	33.931	3.483	3.856	3.223	3.439	20.202
86	.39	1.21	3.65	7.32	28.42	28.95	1.67	1.70	14.21	14.47	5.458	10.967	42.555	43.343	2.503	2.550	3.355	3.417	20.202
97	.28	.87	3.65	4.39	16.72	20.44	0.00	0.00	9.36	10.22	10.697	12.897	49.063	59.966	0.000	0.000	3.095	3.377	20.202
88	.17	.52	0.00	3.66	9.03	9.20	0.00	0.00	4.51	4.60	0.000	29.854	73.595	74.959	0.000	0.000	2.487	2.533	20.202
99	3.20	5.03	298.92	76.91	91.96	49.39	100.32	61.31	33.63	57.90	6.489	1.669	1.996	1.072	2.177	1.331	5.323	3.291	57.584
91	2.37	3.72	47.39	58.63	230.73	126.02	56.85	42.57	55.17	35.76	1.879	2.324	9.150	4.997	2.254	1.699	4.240	2.748	57.584
91	1.55	2.44	14.22	3.66	110.35	85.15	26.75	30.65	23.41	27.25	1.313	.338	10.194	7.866	2.471	2.832	2.745	3.196	57.584
93	2.95	3.09	247.99	80.57	95.27	25.54	93.63	34.06	53.50	23.84	6.367	2.069	2.190	.656	2.405	.875	4.963	2.211	91.871
94	2.10	2.20	29.16	62.26	31.77	20.44	60.19	17.03	36.78	17.03	1.469	3.134	1.599	1.029	3.033	.857	4.777	2.211	91.871
95	1.23	1.29	10.75	20.14	86.94	53.13	26.75	10.22	13.38	10.22	1.573	2.946	12.716	7.771	3.911	1.494	2.361	2.262	91.871
96	.64	.67	6.56	5.49	24.08	19.75	6.63	4.26	6.69	6.41	3.616	3.028	13.269	10.887	3.695	2.346	2.974	2.927	91.871

Table 13 - Wave Force Tests Data and Calculated Results for Series 9; h = 8 ft, $\phi = 0^{0}$

* SERIES NO.9 , RUN 97-108 DATA 8/ 1/77 PAGE 9

WATER DEPTH= 8.0FEET FLANGE ANGLE= 0.0DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	RE**5	K
97	1.90	2.00	0.00	1.65	14.47	14.47	0.00	0.00	14.47	14.47	0.000	1.412	12.405	12.405	0.000	0.000	2.585	2.585	.230	2.056
98	1.44	2.00	.84	1.65	9.95	10.95	0.00	0.00	9.95	10.95	1.251	2.466	14.892	16.245	0.000	0.000	2.348	2.562	.174	1.556
99	.97	2.00	0.00	0.00	7.05	6.87	0.00	0.00	7.05	6.87	0.000	0.000	22.933	22.345	0.000	0.000	2.454	2.391	.118	1.056
100	.69	2.00	0.00	0.00	3.62	3.98	0.00	0.00	3.62	3.98	0.000	0.000	23.295	25.624	0.000	0.000	1.771	1.948	.084	.750
101	3.90	4.00	173.83	23.72	44.85	36.17	25.32	18.08	28.94	36.17	4.015	.548	1.036	.835	.585	.418	1.697	2.121	1.400	25.060
101	3.92	4.00	167.15	15.47	54.25	38.34	32.55	14.47	28.94	36.17	3.820	.376	1.240	.876	.744	.331	1.588	2.110	1.407	25.192
102	2.87	4.00	20.06	14.50	29.66	26.40	7.23	7.23	25.32	26.40	.853	.617	1.262	1.123	.308	.308	2.015	2.101	1.031	18.465
103	1.90	4.00	10.03	17.13	16.28	19.89	3.62	3.62	16.28	19.89	.977	1.669	1.586	1.938	.352	.352	1.361	2.396	.681	12.200
104	.90	4.00	2.51	4.34	8.68	8.14	.90	.90	8.68	8.14	1.080	2.128	3.739	3.505	.389	.389	2.198	2.061	.324	5.803
105	3.18	6.00	157.12	9.38	39.79	18.08	21.70	14.47	18.08	18.08	4.167	.262	1.055	.480	.575	.384	1.705	1.705	1.306	35.080
106	2.24	6.00	6.69	6.12	25.32	12.66	14.47	7.23	18.09	12.66	.359	.371	1.358	.679	.776	.388	2.424	1.697	.919	24.669
107	1.33	6.00	6.69	5.77	14.47	8.14	3.62	1.81	12.66	8.14	1.008	.869	2.182	1.227	.545	.273	2.845	1.829	.548	14.711
108	.67	6.00	1.67	3.62	4.52	3.98	.90	.90	4.52	3.98	1.009	2.186	2.727	2.400	.545	.545	2.032	1.789	.274	7.355

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	WL-FT
97	.51	1.60	0.00	3.66	28.42	27.25	0.00	0.00	14.21	13.62	0.000	3.140	24.370	23.362	0.000	0.000	2.539	2.434	20.202
98	.39	1.21	1.82	4.03	19.39	18.73	0.00	0.00	9.70	9.37	2.729	6.032	29.037	28.045	0.000	0.000	2.289	2.211	20.202
99	.26	.82	0.00	1.83	13.38	13.28	0.00	0.00	6.69	6.64	0.000	5.954	43.491	43.189	0.000	0.000	2.327	2.311	20.202
100	.19	.58	0.00	0.00	6.69	6.47	0.00	0.00	3.34	3.24	0.000	0.000	43.073	41.677	0.000	0.000	1.637	1.584	20.202
101	3.11	4.88	176.80	21.37	46.81	27.25	26.75	0.00	33.44	27.25	4.043	.508	1.091	.623	.618	0.000	1.961	1.598	57.584
101	3.12	4.90	167.69	25.64	46.15	26.37	26.75	6.81	33.44	23.84	3.832	.586	1.055	.607	.611	.156	1.951	1.391	57.584
102	2.29	3.59	4.56	10.07	28.42	26.57	10.03	3.41	26.75	26.57	.194	.428	1.209	1.130	.427	.145	2.129	2.114	57.584
103	1.51	2.39	29.16	54.94	40.13	34.06	3.34	3.41	20.06	17.03	2.842	5.353	3.910	3.313	.326	.332	2.417	2.051	57.584
104	.72	1.13	3.65	9.89	15.38	16.35	.94	.85	7.69	9.17	1.570	4.259	6.624	7.043	.363	.367	1.949	2.070	57.584
105	2.90	3.04	167.69	19.31	40.13	20.44	13.33	0.00	20.06	20.44	4.447	.486	1.064	.542	.355	0.000	1.391	1.926	91.871
106	2.04	2.13	21.97	56.[illegible]	43.47	18.34	13.34	0.00	16.72	9.29	1.173	3.075	2.311	.986	.717	0.100	2.241	1.233	91.871
107	1.22	1.27	14.54	30.03	28.42	13.62	3.34	0.00	11.70	6.81	2.191	4.524	4.296	2.054	.504	0.000	2.631	1.531	91.871
108	.61	.64	4.74	7.32	8.36	7.49	.94	1.00	4.19	3.73	2.959	4.418	5.043	4.520	.504	0.000	1.479	1.684	91.871

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Table 14 - Wave Force Tests Data and Calculated Results for Series 10; h = 8 ft, $\phi = 45^{o}$

* SERIES NO.10, RUN 109-120   DATA 8/ 1/77

WATER DEPTH= 8.0FEET   FLANGE ANGLE= 45.0DEGREE   TOTAL VOLUME= 1.8017 FT3   LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	CDC	CDT	CI+	CI-	RE**5	K
109	1.95	2.00	2.01	4.61	15.91	16.29	1.81	1.81	15.91	16.28	1.817	4.178	14.414	14.741	1.639	1.638	2.922	2.989	.224	2.001
110	1.44	2.00	.84	1.55	11.75	12.66	0.00	0.00	11.75	12.66	1.251	2.466	17.599	18.953	0.000	0.000	2.775	2.989	.174	1.556
111	1.03	2.00	0.00	0.00	8.14	8.14	0.00	0.00	8.14	8.14	0.000	0.000	23.881	23.881	0.000	0.000	2.690	2.690	.124	1.112
112	.68	2.00	0.00	0.00	3.98	4.52	0.00	0.00	3.98	4.52	0.000	0.000	26.802	30.457	0.000	0.000	1.992	2.264	.082	.734
113	4.00	4.00	157.12	79.67	122.97	68.72	96.81	28.94	54.25	43.40	3.445	1.734	2.696	1.507	1.903	.634	3.100	2.480	1.437	25.719
114	2.82	4.00	93.60	56.01	65.83	54.25	48.83	21.70	43.40	28.94	4.128	2.470	2.903	2.393	2.153	.957	3.517	2.345	1.013	18.135
115	1.79	4.00	40.12	39.54	28.94	32.55	13.39	16.28	23.51	25.32	4.369	4.306	3.151	3.545	1.457	1.772	2.994	3.224	.645	11.541
116	.92	4.00	9.36	14.00	10.85	12.12	1.81	4.16	9.04	11.75	3.854	5.765	4.468	4.989	.745	1.713	2.239	2.911	.332	5.935
117	3.18	6.00	117.00	29.65	108.51	39.79	79.57	25.32	47.02	21.70	3.103	.786	2.477	1.055	2.110	.671	4.432	2.846	1.306	35.080
118	2.26	6.00	75.22	20.43	59.68	28.94	41.59	10.85	25.32	14.47	3.960	1.076	3.142	1.524	2.190	.571	3.363	1.922	.927	24.895
119	1.38	6.00	36.77	14.83	25.32	21.70	17.00	9.32	14.47	9.04	5.142	2.073	3.540	3.035	2.377	1.163	3.131	1.957	.569	15.277
120	.69	6.00	5.85	7.41	7.23	5.43	1.81	3.62	5.43	5.43	3.321	4.209	4.107	3.080	1.027	2.053	2.366	2.366	.282	7.592

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	CDC	CDT	CI+	CI-	WL-FT
109	.50	1.56	3.65	9.89	30.10	30.65	1.67	1.70	15.05	15.33	3.302	8.956	27.257	27.762	1.514	1.542	2.763	2.814	20.202
110	.39	1.21	1.82	3.66	23.41	22.14	0.00	0.00	11.70	11.07	2.729	5.483	35.045	33.145	0.000	0.000	2.763	2.613	20.202
111	.28	.87	0.00	0.00	16.72	17.03	0.00	0.00	8.36	8.51	0.000	0.000	49.063	49.972	0.000	0.000	2.763	2.814	20.202
112	.19	.57	0.00	0.00	6.69	9.54	0.00	0.00	3.34	4.77	0.000	0.000	45.053	64.243	0.000	0.000	1.675	2.388	20.202
113	3.19	5.01	167.69	53.11	117.04	64.71	76.91	30.65	46.81	42.91	3.677	1.164	2.566	1.419	1.686	.672	2.675	2.452	57.584
114	2.25	3.53	185.91	168.47	127.07	105.58	45.14	22.14	40.13	27.25	8.199	7.430	5.604	4.656	1.991	.976	3.252	2.208	57.584
115	1.43	2.25	83.94	98.89	60.19	61.31	13.39	13.62	20.06	20.44	9.131	10.769	6.555	6.676	1.457	1.484	2.555	2.602	57.584
116	.74	1.16	17.86	27.47	21.74	20.44	1.67	3.41	9.20	10.22	7.355	11.310	8.949	8.414	.683	1.402	2.277	2.530	57.584
117	2.90	3.94	158.57	27.47	113.69	34.06	70.22	15.67	40.13	14.99	4.205	.728	3.015	.903	1.862	.415	3.782	1.413	91.871
118	2.06	2.15	149.46	96.69	117.04	54.49	43.47	8.51	23.41	13.62	7.870	5.091	6.163	2.869	2.289	.448	3.109	1.809	91.871
119	1.26	1.32	78.55	54.94	50.16	40.97	16.72	5.11	13.38	5.79	10.705	7.682	7.014	5.715	2.338	.714	2.495	1.253	91.871
120	.63	.66	14.59	14.65	15.05	11.92	1.67	3.41	5.02	5.96	8.278	8.317	8.543	6.767	.943	1.934	2.187	2.599	91.871

Table 15 - Wave Force Tests Data and Calculated Results for Series 11; h = 8 ft, $\phi = 0^0$

* SERIES NO.11. RUN 121-132 DATA 8/ 1/77

WATER DEPTH= 8.0FEET FLANGE ANGLE= 0.0DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	COC	COT	CI+	CI-	RE**5	K
121	1.90	2.00	1.67	1.67	13.56	13.56	0.00	0.00	13.56	13.56	1.433	1.412	11.629	11.629	0.000	0.000	2.423	2.423	.230	2.056
122	1.46	2.00	1.67	1.65	10.85	11.21	0.00	0.00	10.85	11.21	2.433	2.397	15.791	16.317	0.000	0.000	2.525	2.610	.176	1.578
123	1.09	2.00	0.00	0.00	7.23	7.23	0.00	0.00	7.23	7.23	0.000	0.000	19.254	19.254	0.000	0.000	2.277	2.277	.130	1.167
124	.64	2.00	0.00	0.00	3.62	3.98	0.00	0.00	3.62	3.98	0.000	0.000	27.171	29.888	0.000	0.000	1.913	2.104	.078	.695
125	3.95	4.00	260.75	30.97	47.02	36.17	21.70	14.47	28.94	32.55	5.867	.697	1.058	.814	.488	.326	1.675	1.884	1.418	25.389
126	2.77	4.00	13.37	19.77	30.74	28.94	10.85	7.23	25.32	28.94	.612	.904	1.406	1.324	.496	.331	2.090	2.388	.995	17.806
127	1.85	4.00	13.37	16.47	16.28	23.51	3.62	7.23	16.28	23.51	1.376	1.696	1.675	2.420	.372	.745	2.015	2.911	.663	11.870
128	.92	4.00	1.67	4.12	7.23	10.85	0.00	0.00	7.23	10.85	.688	1.696	2.978	4.469	0.000	0.000	1.791	2.687	.332	5.935
129	3.19	6.00	200.58	13.18	43.40	18.08	21.70	18.08	21.70	18.08	5.319	.349	1.151	.480	.575	.480	2.046	1.705	1.306	35.080
130	1.87	6.00	8.36	6.59	28.94	10.85	10.85	7.23	14.47	10.85	.643	.507	2.226	.835	.835	.557	2.323	1.742	.767	20.595
131	1.44	6.00	8.36	4.94	14.47	9.04	.90	0.00	14.47	9.04	1.087	.643	1.881	1.176	.118	0.000	3.020	1.887	.590	15.842
132	.72	6.00	2.94	4.79	2.71	6.33	1.81	1.81	2.71	6.33	1.478	2.485	1.411	3.292	.941	.941	1.132	2.642	.295	7.921

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	COC	COT	CI+	CI-	WL-FT
121	.51	1.60	3.65	5.43	25.08	25.54	0.00	0.00	12.54	12.77	3.126	4.710	21.503	21.901	0.000	0.000	2.240	2.282	20.202
122	.39	1.23	3.65	3.66	20.73	22.14	0.00	0.00	10.37	11.07	5.305	5.330	30.172	32.217	0.000	0.000	2.413	2.576	20.202
123	.29	.91	0.00	0.00	13.38	13.62	0.00	0.00	6.69	6.81	0.000	0.000	35.601	36.261	0.000	0.000	2.105	2.144	20.202
124	.17	.54	0.00	0.00	6.02	6.81	0.00	0.00	3.01	3.41	0.000	0.000	45.217	51.171	0.000	0.000	1.591	1.801	20.202
125	3.15	4.94	255.18	12.09	38.79	30.65	20.05	13.62	26.75	30.65	5.741	.272	.873	.690	.451	.307	1.548	1.774	57.584
126	2.21	3.47	3.65	10.99	30.13	23.84	10.03	3.41	26.75	20.44	.167	.503	1.377	1.091	.459	.156	2.209	1.687	57.584
127	1.47	2.31	21.97	49.81	33.44	35.42	3.34	3.41	16.72	17.71	2.251	5.127	3.442	3.646	.344	.351	2.070	2.193	57.584
128	.74	1.16	3.65	10.99	15.05	15.33	0.00	0.00	7.52	7.66	1.501	4.524	6.196	6.310	0.000	0.000	1.463	1.897	57.584
129	2.90	3.04	236.[illegible]	19.31	41.46	10.22	20.06	10.22	20.06	10.22	6.284	.486	1.100	.271	.532	.271	1.591	.963	91.871
130	1.70	1.79	25.52	54.94	11.70	6.81	10.03	3.41	13.38	13.62	1.963	4.227	.300	.524	.772	.262	2.147	2.187	91.871
131	1.31	1.37	18.23	29.30	23.41	15.33	0.00	0.00	11.70	7.66	2.370	3.810	3.044	1.993	0.000	0.000	2.443	1.599	91.871
132	.65	.63	6.56	6.51	9.36	8.51	1.17	1.19	4.19	4.26	3.413	3.429	4.349	4.429	.609	.620	1.745	1.777	91.871

Table 16 - Wave Force Tests Data and Calculated Results for Series 12; h = 8 ft, ϕ = -45^{0}

* SERIES NO.12, RUN 133-144 DATA 8/ 1/77 , 130.AM-1130AM

WATER DEPTH= 8.0FEET FLANGE ANGLE=-45.0DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	RE**5	K
133	1.90	2.00	5.01	7.41	16.29	15.73	1.81	1.81	16.29	15.73	4.299	6.356	13.955	13.490	1.551	1.551	2.908	2.811	.230	2.056
134	1.44	2.00	3.01	4.61	12.66	13.56	0.00	0.00	12.66	13.56	4.505	6.906	14.953	20.307	0.000	0.000	2.389	3.202	.174	1.556
135	1.03	2.00	1.67	2.64	7.60	8.68	0.00	0.00	7.60	8.68	4.905	7.735	22.299	25.473	0.000	0.000	2.510	2.869	.124	1.112
136	.66	2.00	.84	.82	3.62	4.16	0.00	0.00	3.62	4.16	5.987	5.901	25.912	29.799	0.000	0.000	1.868	2.148	.079	.711
137	3.85	4.00	76.89	105.43	126.59	65.10	57.87	34.00	39.79	39.79	1.823	2.500	3.002	1.544	1.372	.806	2.364	2.364	1.381	24.730
138	2.87	4.00	61.84	81.39	77.76	39.06	30.74	21.70	28.94	34.36	2.631	3.462	3.308	1.662	1.308	.923	2.303	2.735	1.031	18.465
139	.97	4.00	10.36	13.51	10.13	11.75	4.52	4.52	9.04	10.85	4.784	6.235	4.675	5.426	2.087	2.087	2.371	2.845	.313	5.605
140	1.90	4.00	26.74	44.48	39.06	29.66	19.89	10.85	18.08	23.51	2.606	4.334	3.806	2.890	1.938	1.057	2.178	2.832	.681	12.200
141	3.23	6.00	26.74	82.37	108.51	34.00	57.87	21.70	28.94	21.70	.687	2.116	2.787	.873	1.486	.557	2.684	2.013	1.327	35.645
142	2.26	6.00	27.75	59.96	41.59	24.59	34.36	15.55	23.51	14.47	1.461	3.157	2.190	1.295	1.809	.819	3.122	1.922	.927	24.895
143	1.39	6.00	13.37	29.65	25.32	14.47	18.08	9.04	10.85	10.85	1.870	4.146	3.540	2.023	2.529	1.264	2.349	2.349	.569	15.277
144	.67	6.00	5.52	8.24	7.23	5.43	3.62	1.81	5.43	5.43	3.327	4.968	4.363	3.273	2.182	1.091	2.439	2.439	.274	7.355

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	WL-FT
133	.51	1.60	14.58	15.38	30.10	32.36	1.67	1.70	15.05	16.15	12.502	13.189	25.804	27.742	1.434	1.460	2.688	2.890	20.202
134	.39	1.21	9.11	10.25	21.74	23.84	0.00	0.00	10.87	11.92	13.645	15.353	32.542	35.694	0.000	0.000	2.566	2.814	20.202
135	.29	.87	4.01	5.49	15.05	14.65	0.00	0.00	7.32	7.32	11.767	16.121	44.157	42.376	0.000	0.000	2.487	2.420	20.202
136	.18	.55	3.65	1.83	8.36	10.22	0.00	0.00	4.18	5.11	26.116	13.119	59.892	73.201	0.000	0.000	2.159	2.638	20.202
137	3.07	4.81	89.31	60.47	133.76	44.28	60.19	25.20	36.78	37.46	2.118	1.433	3.172	1.050	1.427	.598	2.186	2.226	57.584
138	2.29	3.59	67.80	166.27	161.85	74.93	28.42	14.65	26.75	28.95	2.884	7.073	6.885	3.187	1.203	.623	2.129	2.304	57.584
139	.69	1.09	18.96	26.37	20.73	20.44	5.02	3.41	9.20	8.51	8.750	12.172	9.570	9.433	2.315	1.572	2.411	2.232	57.584
140	1.51	2.38	36.45	100.35	73.57	54.49	16.72	6.81	18.39	20.44	3.552	9.779	7.169	5.310	1.629	.664	2.215	2.461	57.584
141	2.95	3.05	82.02	47.61	110.35	27.25	56.55	17.03	26.75	20.44	2.107	1.223	2.834	.700	1.460	.437	2.481	1.896	91.871
142	2.06	2.15	68.51	79.38	140.44	37.46	35.11	11.92	20.05	13.62	3.186	4.127	7.395	1.973	1.849	.629	2.665	1.809	91.871
143	1.26	1.32	25.52	70.37	48.82	23.95	15.05	6.81	8.36	10.22	3.568	9.833	6.427	3.334	2.104	.951	1.509	2.211	91.871
144	.61	.64	10.94	16.45	11.02	10.30	2.01	2.04	4.14	5.11	6.597	10.162	6.656	6.574	1.210	1.233	1.479	2.297	91.871

Table 17 - Wave Force Tests Data and Calculated Results for Series 13; h = 6 ft, $\phi = -45^{0}$

* SERIES NO.13, RUN 145-156 DATA 9/ 2/77

WATER DEPTH= 6.0FEET FLANGE ANGLE=-45.0DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	RE**5	K
145	1.85	2.00	14.21	23.06	28.03	28.94	2.71	5.43	28.03	28.94	4.009	6.509	7.910	8.166	.766	1.531	2.873	2.966	.400	3.585
146	1.49	2.00	9.19	14.83	21.70	22.61	5.43	5.43	21.70	22.61	3.998	6.448	9.439	9.831	2.359	2.359	2.761	2.876	.323	2.898
147	.97	2.00	4.18	5.77	14.47	15.91	1.81	1.81	14.47	14.47	4.234	5.841	14.657	16.123	1.832	1.832	2.810	2.810	.211	1.892
148	.67	2.00	.84	1.65	8.14	7.23	0.00	0.00	8.14	7.23	1.809	3.565	17.612	15.655	0.000	0.000	2.310	2.053	.145	1.294
149	2.77	4.00	58.50	98.94	115.74	43.40	61.49	21.70	61.49	25.32	1.765	2.982	3.492	1.309	1.855	.655	4.121	1.697	1.225	21.927
150	2.00	4.00	35.10	72.49	75.95	32.55	47.02	18.08	26.40	30.74	2.030	4.192	4.393	1.883	2.713	1.046	2.450	2.853	.885	15.836
151	1.29	4.00	32.59	28.01	25.32	22.61	13.56	9.04	16.28	18.99	4.587	3.942	3.563	3.182	1.909	1.273	2.356	2.749	.567	10.151
152	.62	4.00	5.01	10.71	10.85	9.04	3.62	2.71	8.14	9.04	3.063	6.541	6.628	5.524	2.209	1.657	2.454	2.727	.272	4.873
153	2.67	6.00	434.59	85.66	115.74	36.89	56.42	14.47	36.17	14.47	11.680	2.302	3.111	.992	1.516	.389	3.432	1.373	1.298	34.846
154	1.74	6.00	70.20	70.84	55.10	25.32	43.40	11.94	21.70	16.28	4.413	4.453	4.093	1.592	2.723	.750	3.149	2.362	.848	22.784
155	1.03	6.00	13.37	32.95	28.94	14.47	21.70	9.04	10.85	10.13	2.429	5.986	5.257	2.629	3.943	1.643	2.677	2.499	.499	13.402
156	.51	6.00	5.01	7.91	8.14	5.43	3.62	2.71	5.06	5.43	3.644	5.747	5.914	3.943	2.629	1.971	2.499	2.677	.250	6.701

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	CDMAX	CDMIN	CDC	CDT	CI+	CI-	WL-FT
145	.83	2.79	23.70	49.44	53.50	51.09	1.67	1.70	26.75	25.54	6.697	13.953	15.099	14.417	.472	.481	2.742	2.618	19.623
146	.72	2.25	18.96	29.30	40.13	40.47	4.19	3.41	20.06	20.44	9.244	12.742	17.451	17.774	1.818	1.481	2.553	2.600	19.623
147	.47	1.47	14.58	12.82	28.42	28.95	1.67	1.70	14.21	14.47	14.773	12.987	28.796	29.330	1.694	1.725	2.760	2.811	19.623
148	.32	1.01	3.65	4.39	15.05	13.62	0.00	0.00	7.52	6.81	7.889	9.511	32.565	29.483	0.000	0.000	2.135	1.933	19.623
149	2.72	4.27	113.01	205.10	230.73	74.33	60.13	20.44	56.95	23.84	3.409	6.187	6.960	2.260	1.816	.616	3.810	1.598	51.295
150	1.36	3.09	83.84	157.49	140.44	66.07	43.47	13.62	26.75	27.25	4.849	9.108	8.122	3.821	2.514	.784	2.482	2.528	51.295
151	1.26	1.99	61.97	64.09	56.85	40.97	16.72	6.81	16.72	17.88	9.722	9.021	9.001	5.752	2.353	.959	2.420	2.588	51.295
152	.60	.95	10.21	25.64	14.39	17.03	3.34	2.55	7.52	8.51	6.235	15.661	11.235	10.403	2.043	1.560	2.269	2.568	51.295
153	2.89	3.02	7.29	51.27	123.72	17.03	33.50	8.86	40.13	13.62	.196	1.378	3.325	.458	1.439	.234	3.808	1.293	80.515
154	1.99	1.97	32.81	99.89	143.79	37.46	35.11	6.81	20.06	13.62	2.063	6.217	9.040	2.355	2.207	.429	2.912	1.977	80.515
155	1.11	1.16	21.87	73.25	60.19	17.03	20.95	3.41	10.03	8.51	3.974	13.308	10.936	3.094	3.645	.619	2.475	2.101	80.515
156	.55	.58	9.84	17.59	15.05	9.54	3.35	2.04	4.19	4.77	7.153	12.778	10.936	6.939	2.735	1.485	2.062	2.353	80.515

Table 18 - Wave Force Tests Data and Calculated Results for Series 14; h = 4 ft, $\phi = -45^{0}$

* SERIES NO.14, RUN 157-168 DATA 8/ 3/77

WATER DEPTH= 4.0FEET FLANGE ANGLE=-45.0DEGREE TOTAL VOLUME= 1.8017 FT3 LENGTH OF PIPE= 9.3333FEET

***** WEST DINAMOMETER *****

RUN	H-FT	T-SEC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	COC	COT	CI+	CI-	RE**5	K
157	1.64	2.00	37.61	55.19	49.73	45.21	28.03	18.08	49.73	45.21	4.225	6.200	5.587	5.080	3.149	2.032	3.216	2.924	.635	5.681
158	1.33	2.00	21.73	37.07	35.26	34.72	10.85	12.66	35.26	34.72	3.698	6.308	6.002	5.909	1.847	2.154	2.807	2.764	.516	4.616
159	.90	2.00	10.03	15.65	23.51	23.51	1.81	3.62	23.51	23.51	3.725	5.813	8.732	8.732	.672	1.343	2.764	2.764	.349	3.125
160	.57	2.00	3.34	3.79	10.85	12.66	1.45	1.81	10.85	12.66	3.066	3.475	9.952	11.610	1.327	1.659	2.005	2.339	.222	1.998
161	2.07	4.00	30.76	93.90	92.23	41.59	81.38	14.47	41.59	41.59	.978	2.985	2.932	1.322	2.587	.460	2.862	2.862	1.193	21.360
162	1.54	4.00	20.73	71.17	56.06	30.74	50.64	16.28	25.32	30.74	1.195	4.103	3.232	1.772	2.919	.938	2.346	2.848	.886	15.861
163	1.00	4.00	13.37	36.24	27.13	17.36	23.51	9.04	16.28	17.36	1.806	4.895	3.664	2.345	3.175	1.221	2.308	2.462	.579	10.363
164	.62	4.00	5.35	12.36	11.39	9.95	6.33	3.80	9.04	9.95	1.927	4.452	4.105	3.584	2.281	1.368	2.894	2.304	.354	6.345
165	2.10	6.00	16.71	107.08	115.74	28.94	34.04	18.08	36.17	28.94	.458	2.936	3.173	.793	2.578	.496	3.466	2.773	1.285	34.501
166	.82	6.00	8.36	33.61	28.94	10.45	21.70	10.85	9.04	7.96	1.505	6.050	5.209	1.953	3.907	1.953	2.221	1.954	.501	13.464
167	1.34	6.00	11.76	70.84	66.91	18.08	57.87	14.47	28.94	18.08	.786	4.756	4.492	1.214	3.885	.971	4.340	2.712	.821	22.047
168	.46	6.00	3.34	8.24	6.87	5.06	3.62	3.62	3.62	5.06	1.902	4.686	3.910	2.881	2.058	2.058	1.579	2.211	.282	7.573

***** EAST DINAMOMETER *****

RUN	VEL	ACC	FV+	FV-	FHMAX	FHMIN	FHC	FHT	FH+	FH-	CL+	CL-	COMAX	COMIN	COC	COT	CI+	CI-	WL-FT
157	1.41	4.42	71.09	120.86	96.94	93.44	21.74	16.18	43.47	41.72	7.986	13.579	9.768	9.375	2.442	1.818	2.811	2.698	18.087
158	1.14	3.59	41.92	76.91	67.88	65.39	10.03	10.22	33.34	35.76	7.135	13.089	11.553	11.129	1.707	1.739	2.781	2.846	18.087
159	.77	2.43	19.23	34.79	43.47	43.59	1.67	1.70	21.74	21.80	6.770	12.922	16.145	16.191	.621	.632	2.556	2.563	18.087
160	.49	1.55	5.47	12.92	21.74	22.14	1.67	1.70	10.87	11.07	5.015	11.756	19.935	20.304	1.533	1.562	2.008	2.045	18.087
161	2.65	4.16	65.62	197.77	167.20	74.93	73.57	11.92	38.46	37.46	2.086	6.287	5.315	2.382	2.339	.379	2.646	2.578	43.049
162	1.97	3.09	33.54	146.50	107.01	55.17	45.81	13.62	26.75	27.59	1.933	8.446	6.169	3.181	2.641	.785	2.478	2.556	43.049
163	1.28	2.02	21.87	79.11	50.16	32.01	18.39	6.81	14.39	15.01	2.954	10.684	6.775	4.324	2.494	.920	2.039	2.270	43.049
164	.79	1.24	10.21	26.37	22.74	15.33	4.69	2.55	10.03	7.66	3.678	9.501	8.193	5.522	1.647	.920	2.324	1.775	43.049
165	2.85	2.99	21.87	234.40	55.17	13.62	93.63	17.03	33.44	27.25	.600	6.426	1.513	.373	2.567	.467	3.205	2.611	66.517
166	1.11	1.16	16.04	77.64	50.16	13.62	21.07	6.81	10.93	5.79	2.868	13.978	9.030	2.453	3.733	1.226	2.464	1.422	66.517
167	1.82	1.91	27.70	157.44	130.41	27.25	56.85	11.92	30.10	13.62	1.860	10.573	8.756	1.829	3.817	.800	4.514	2.843	66.517
168	.63	.66	6.56	17.59	13.39	6.81	3.34	2.55	4.51	3.41	3.733	10.002	7.610	3.876	1.903	1.453	1.371	1.487	66.517

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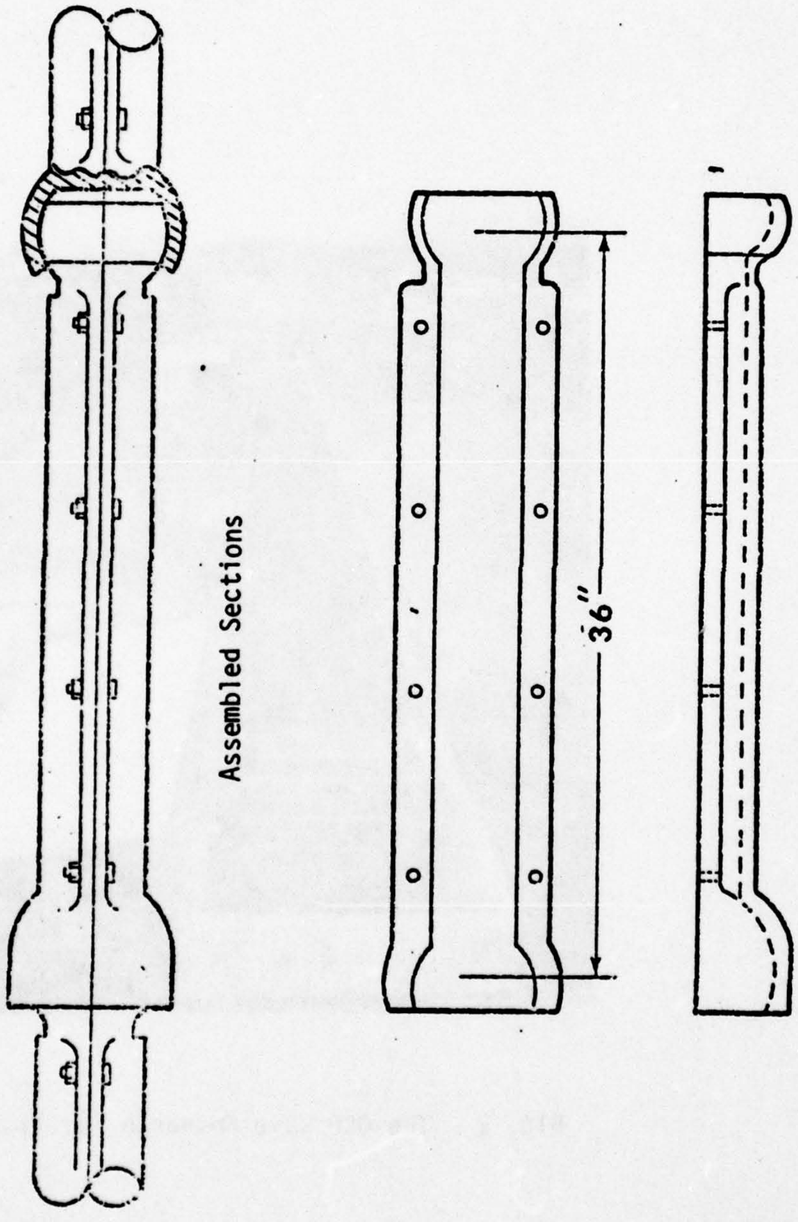
FIG. 1 - Split Pipe



Split Pipe Cable Protector

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FIG. 2 - The OSU Wave Research Facility

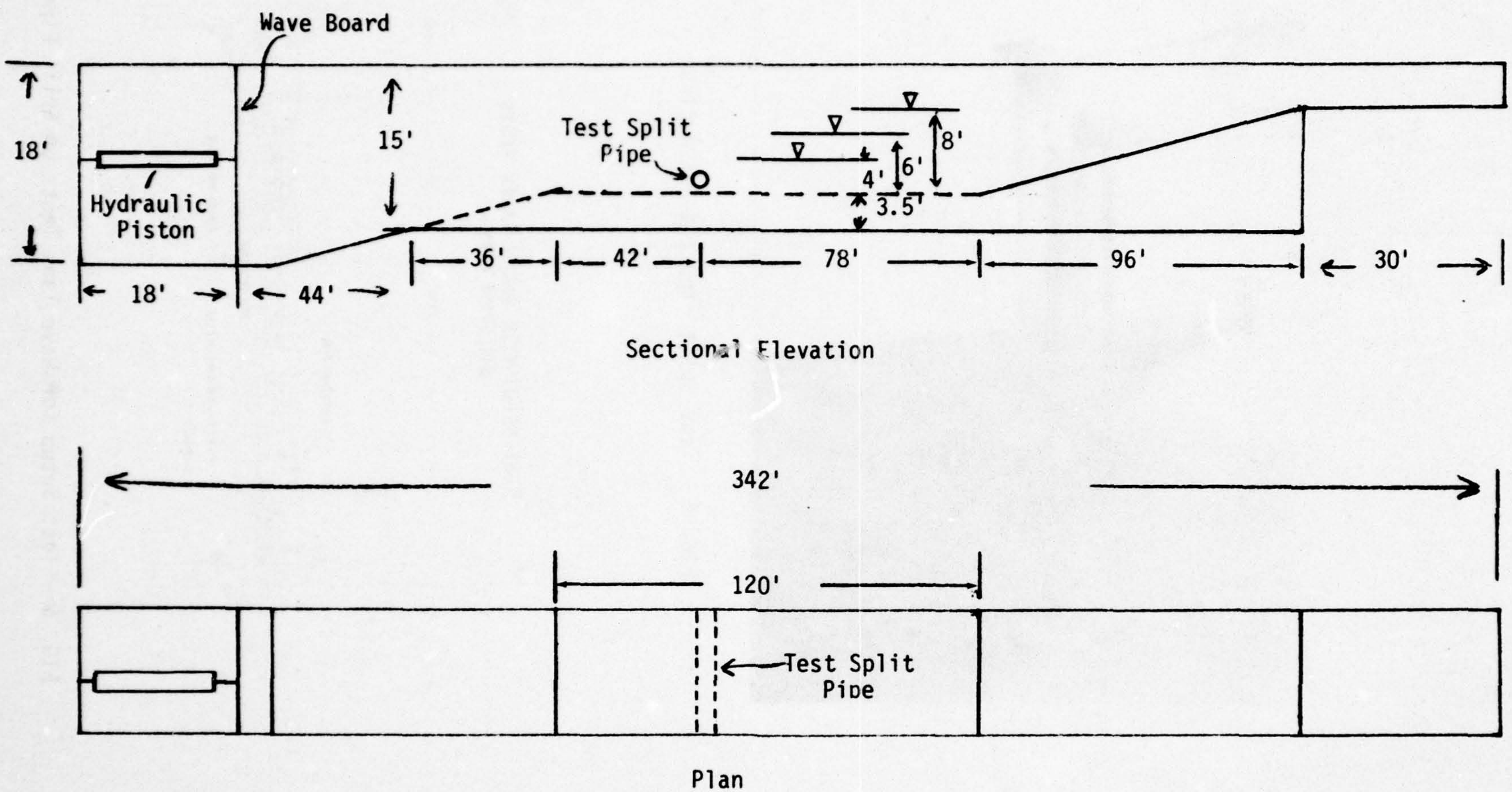

FIG. 3 - Location of Test Split Pipe and False Floor Configuration

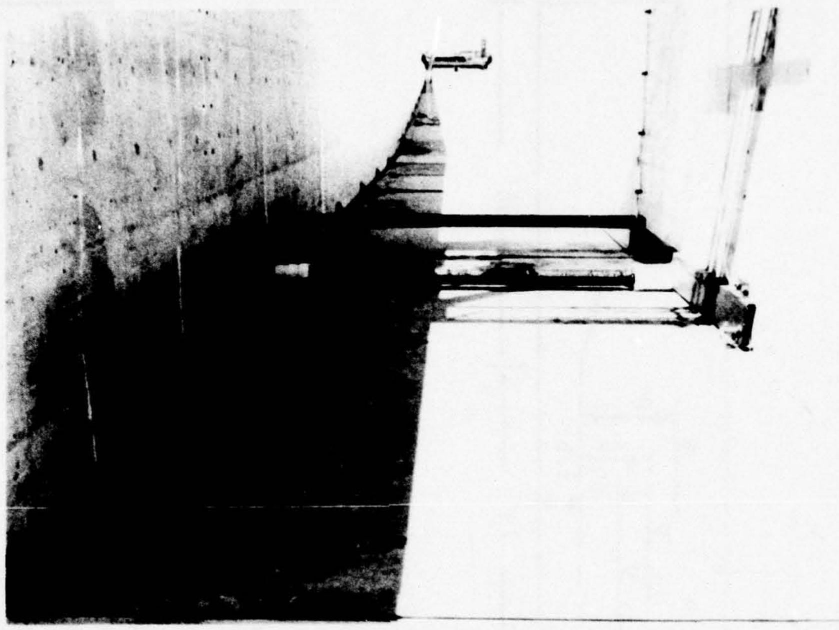

FIG. 4 - Test Split Pipe and False Floor

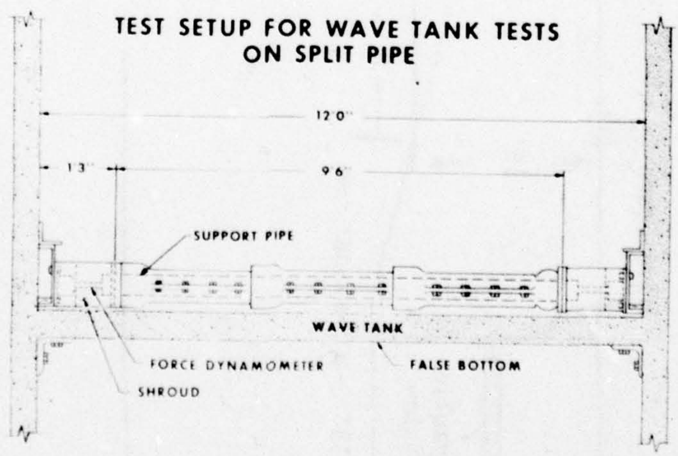

FIG. 5 - Test Setup for Wave Tank Tests on Split Pipe

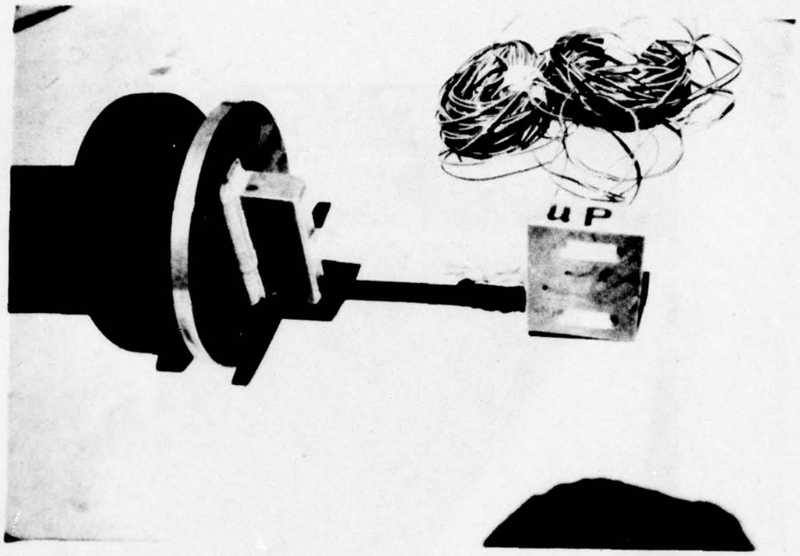

FIG. 6 - Force Dynamometer

FIG. 7 - Underwater Operation of Changing of Flange Angle

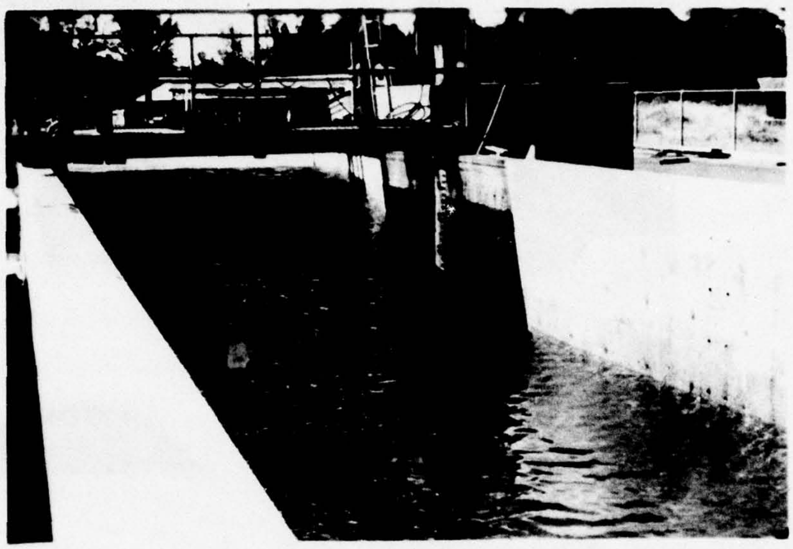

FIG. 8 - The Test Wave With T = 6 sec., H = 3.3 ft., h = 8 ft.

FIG. 9 - The Test Wave With T = 2 sec., H = 1.9 ft., h = 8 ft.

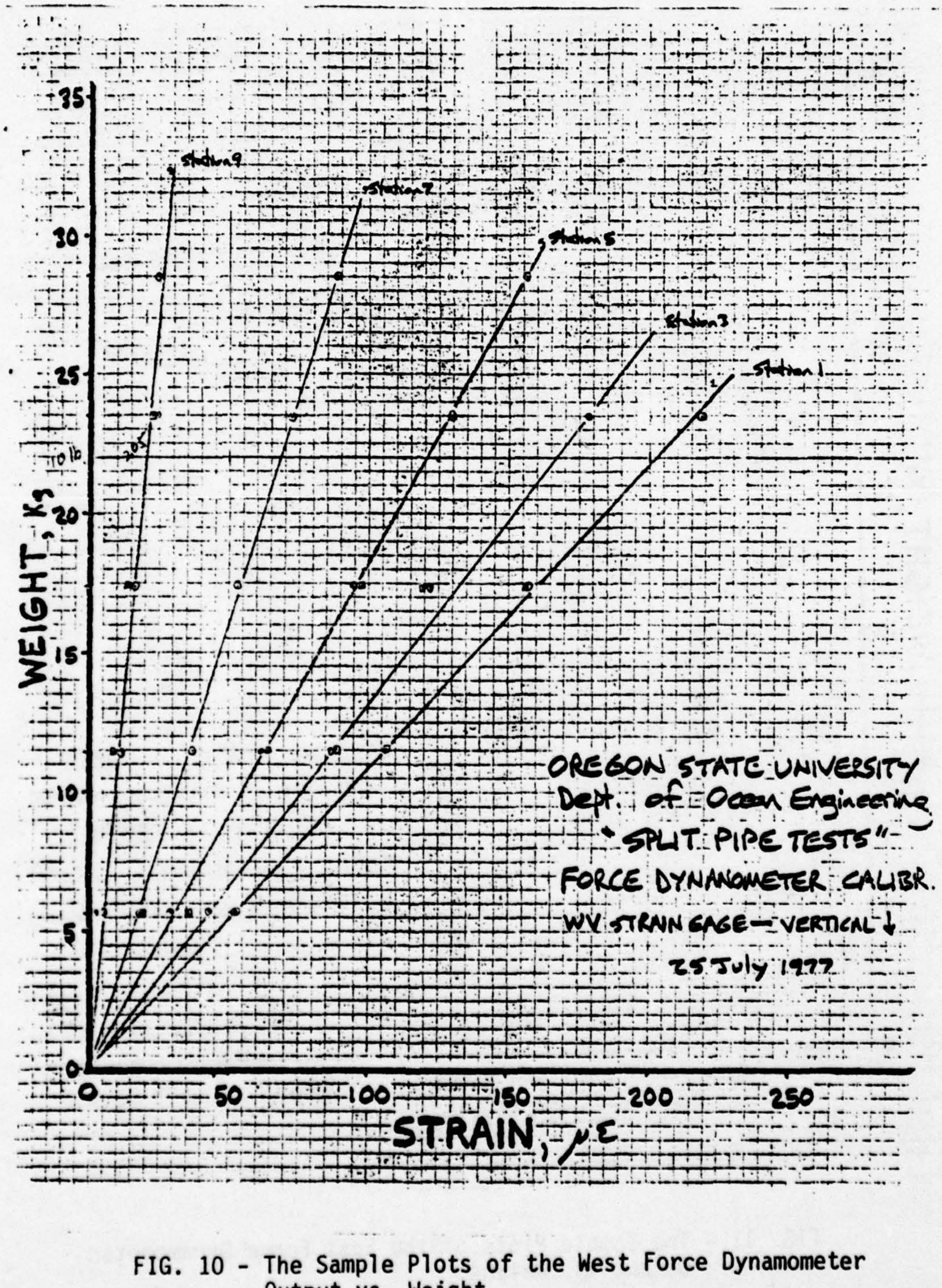

FIG. 10 - The Sample Plots of the West Force Dynamometer Output vs. Weight

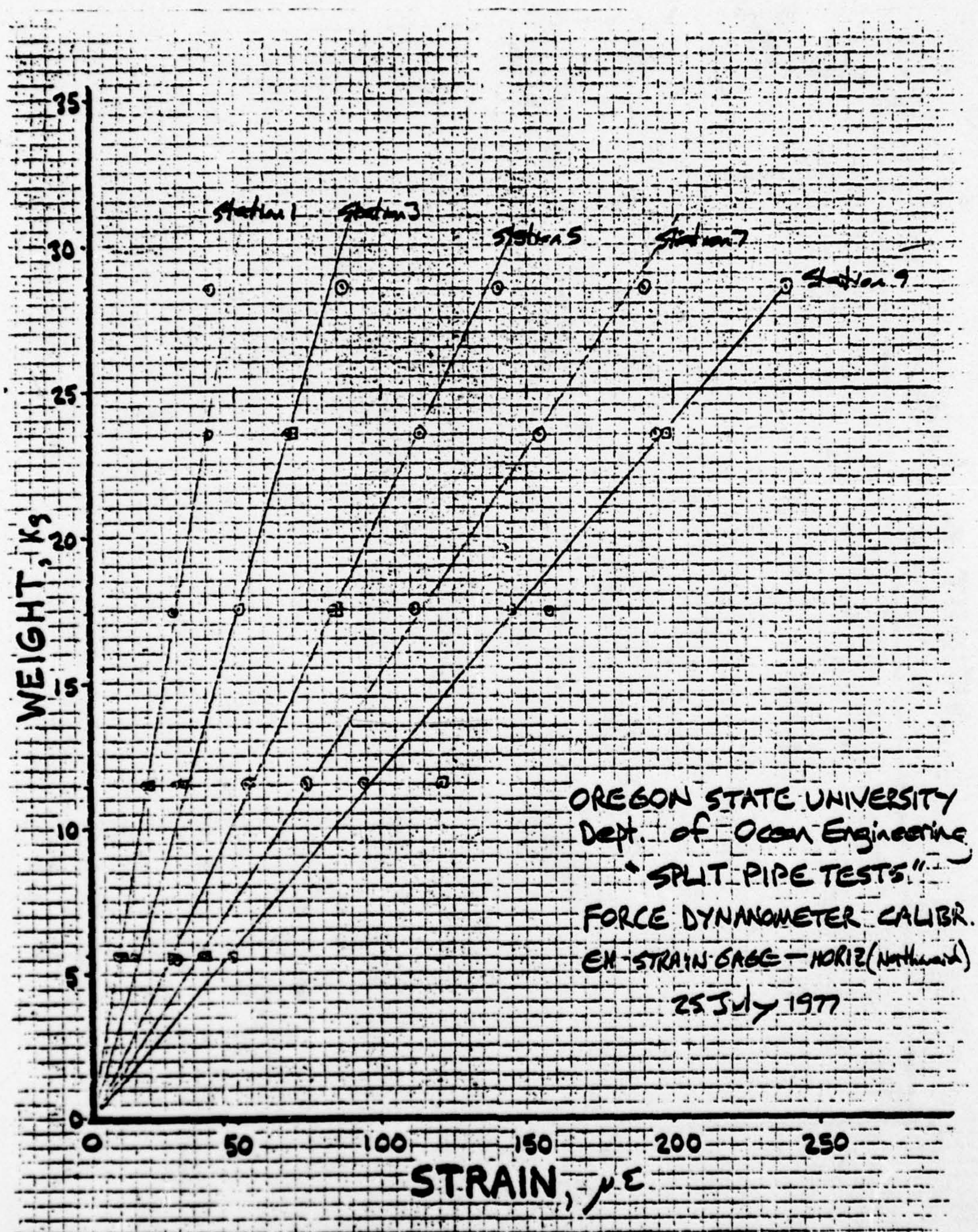

FIG. 11 - The Sample Plots of the East Force Dynamometer Output vs. Weight

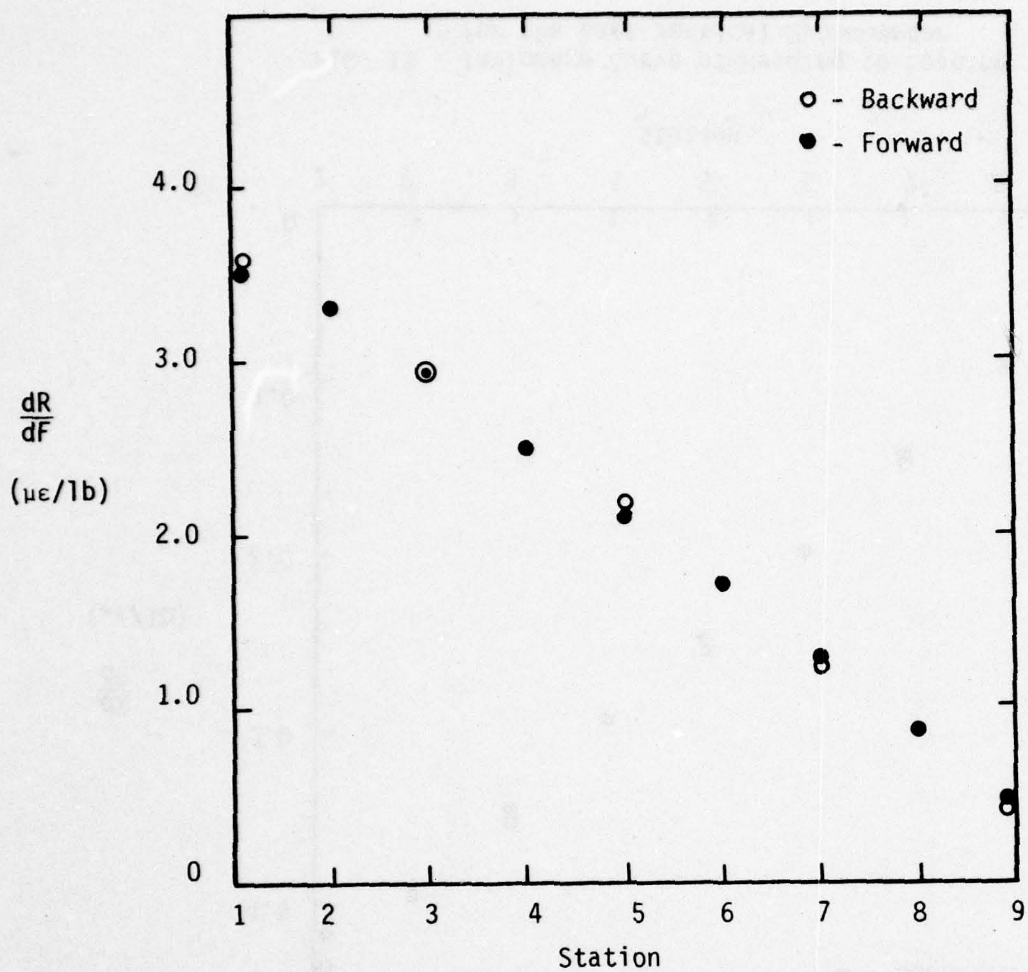

FIG. 12 - Influence Curve of Reading to Loading for the West Horizontal Dynamometer

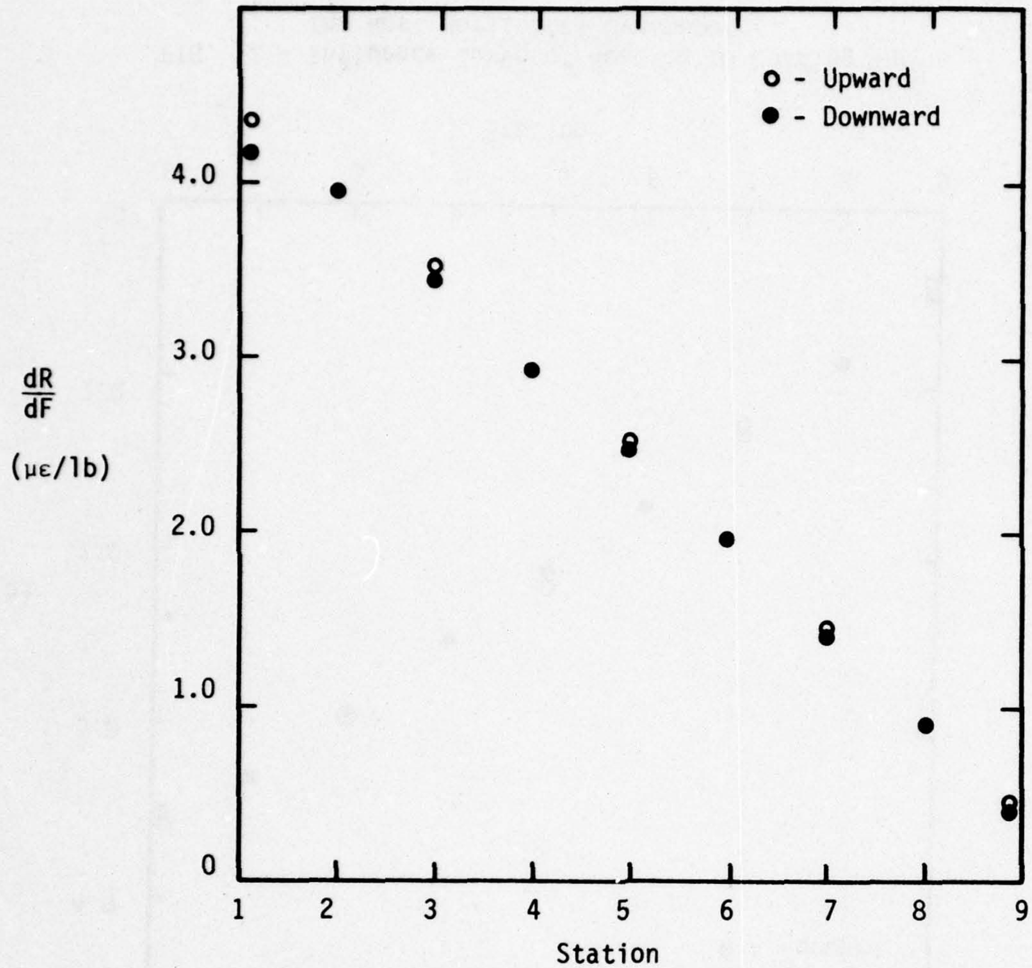

FIG. 13 - Influence Curve of Reading to Loading for the West Vertical Dynamometer

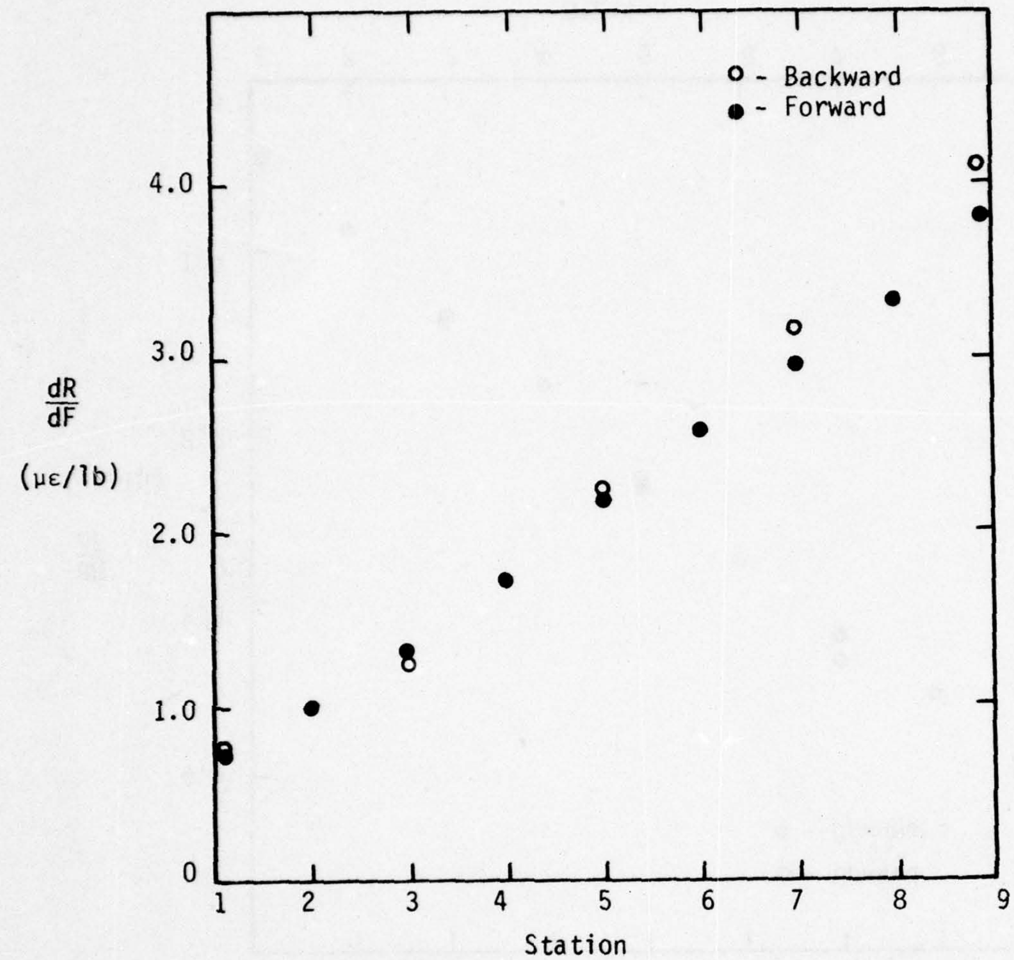

FIG. 14 - Influence Curve of Reading to Loading for the East Horizontal Dynamometer

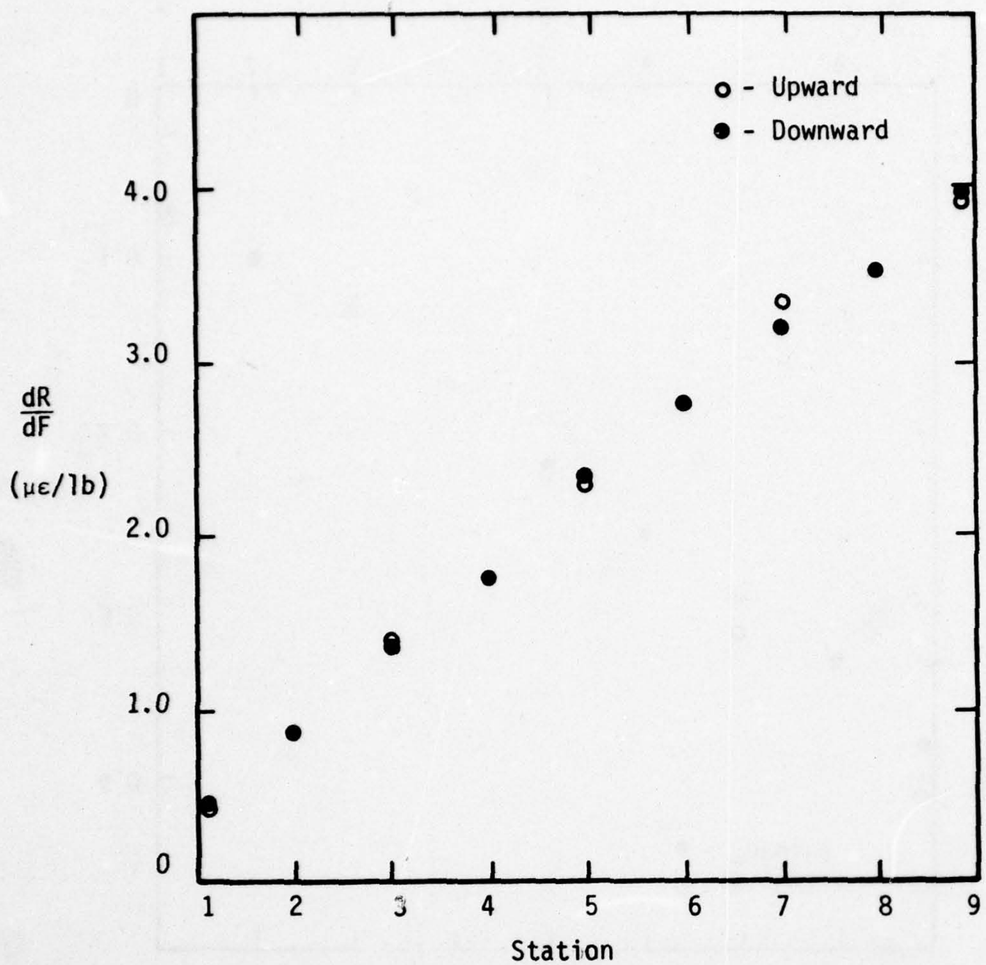

FIG. 15 - Influence Curve of Reading to Loading for the East Vertical Dynamometer

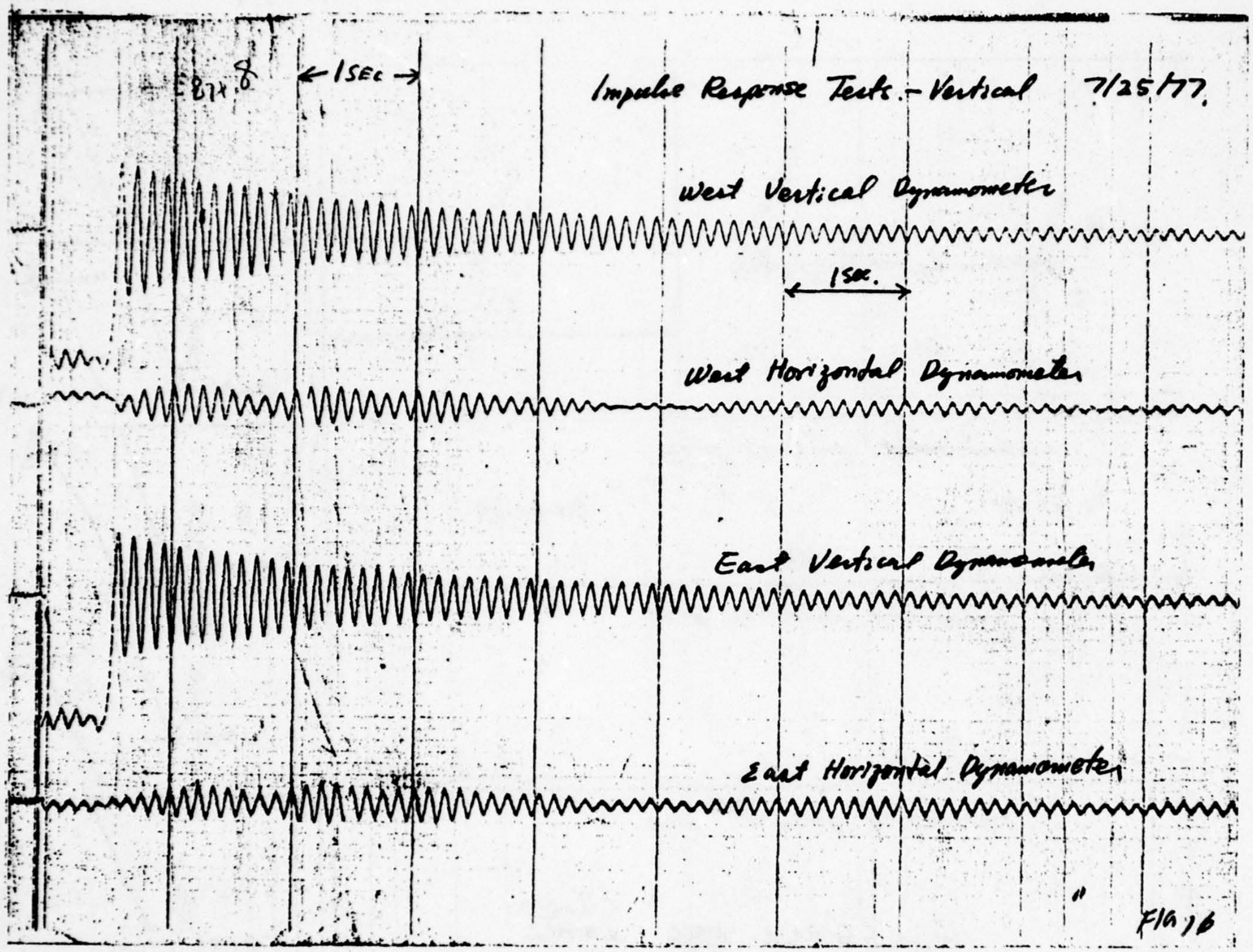

FIG. 16 - Recording of Impulse Response Tests

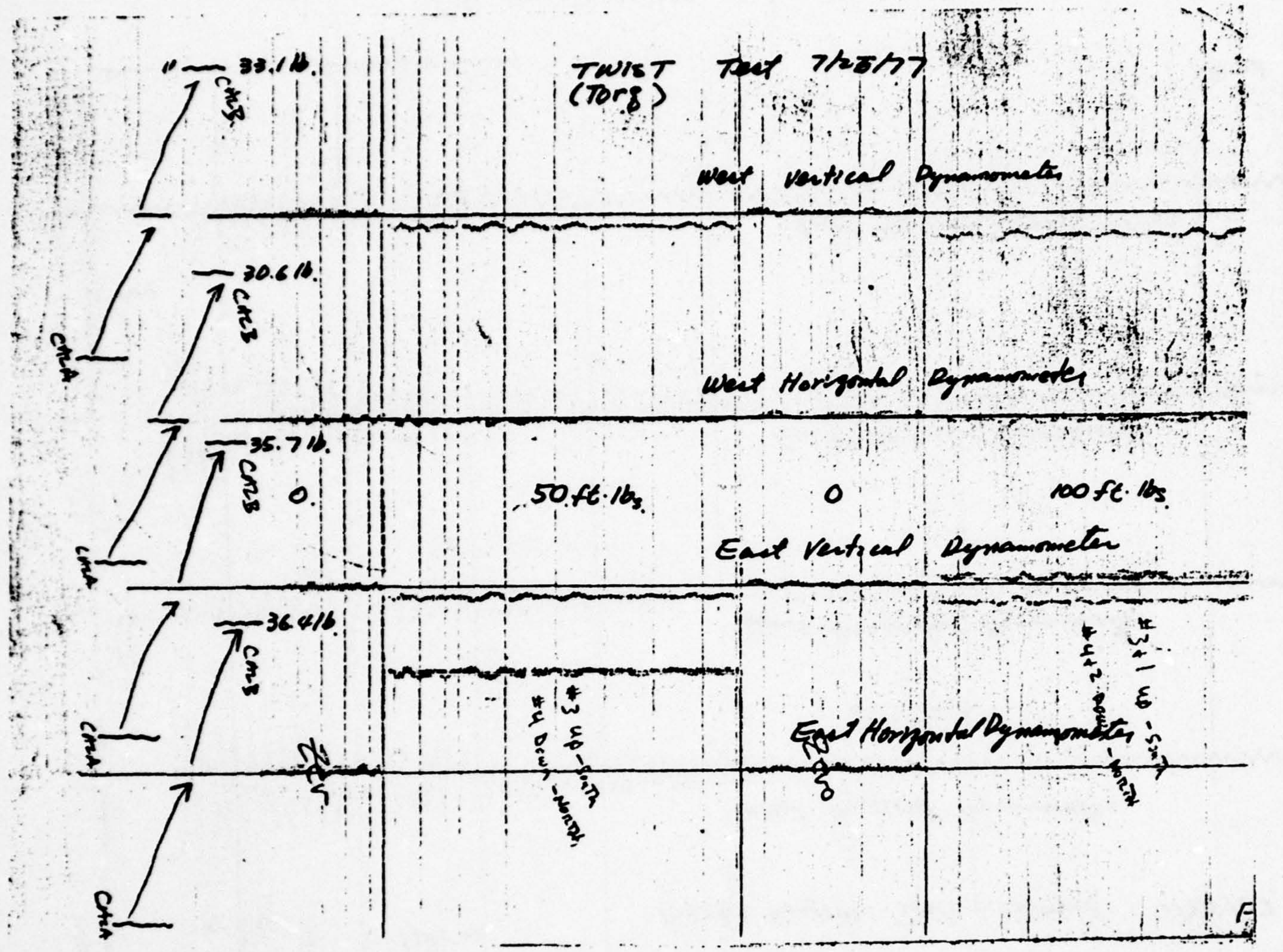

FIG. 17 - Recording of Torque Test

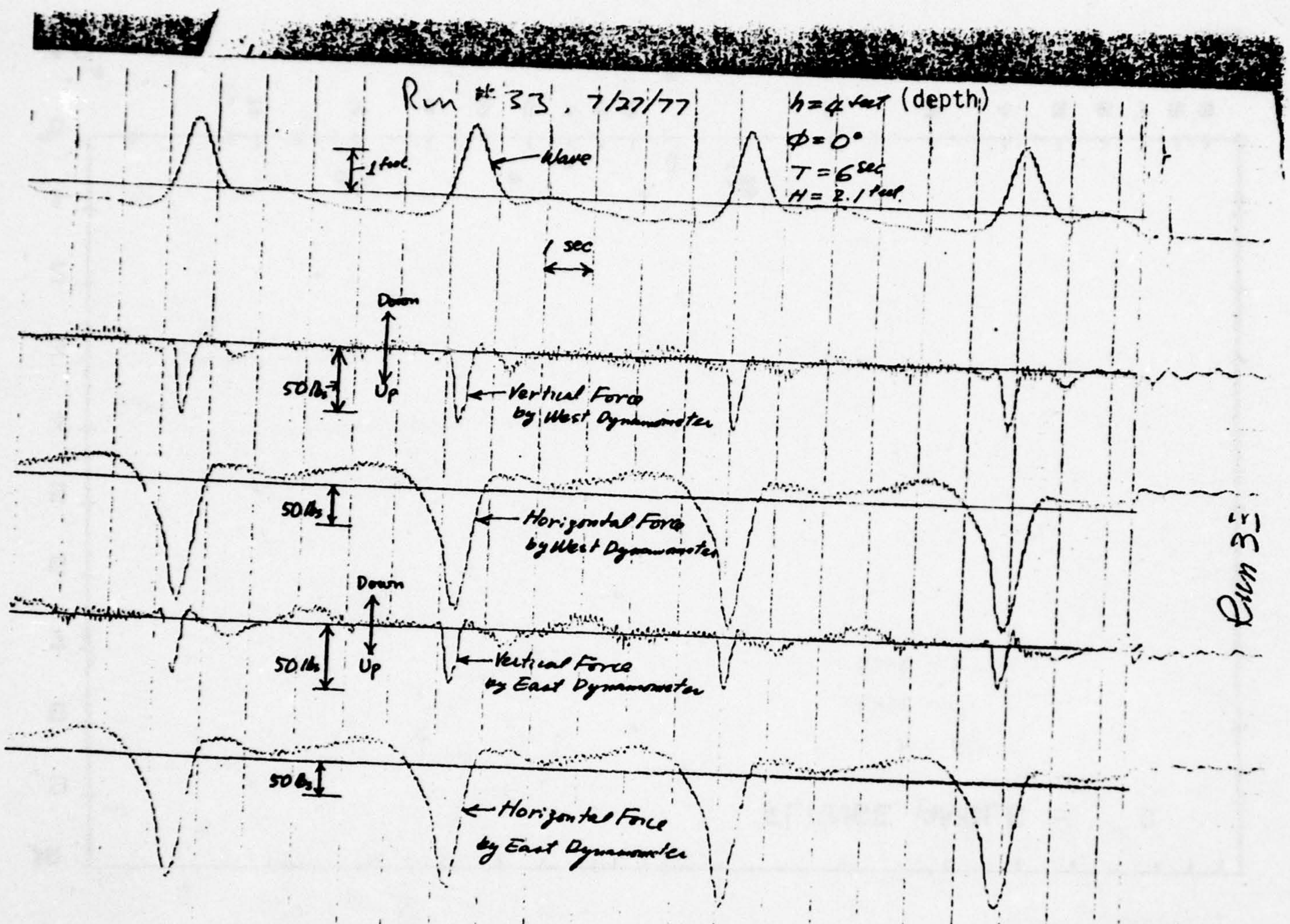

FIG. 18

FIG. 18 - Example Recording of Wave Force Test, Run 33

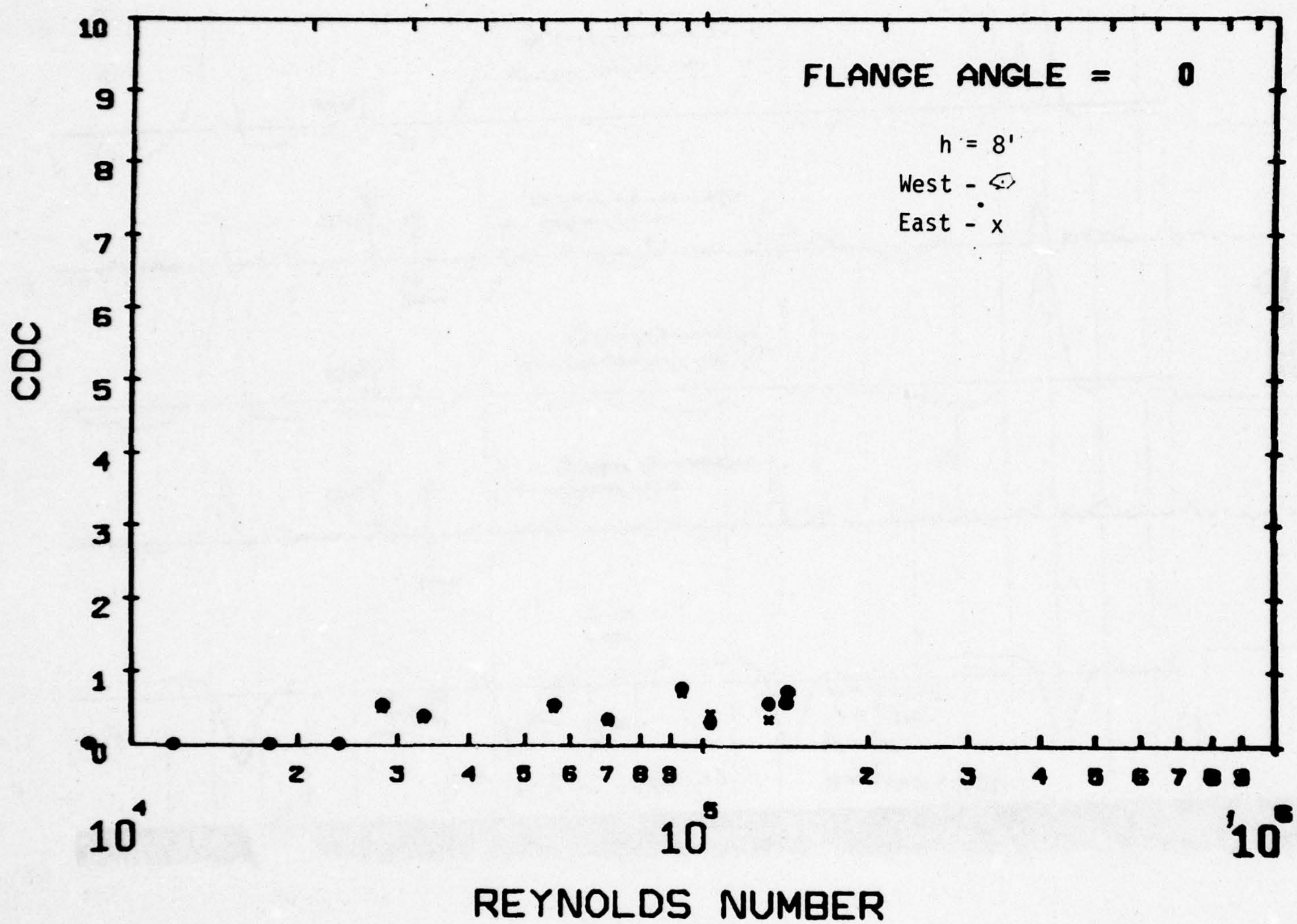

FIG. 19 - Comparison Between West Dynamometer and East Dynamometer for CDC vs. Re, $\phi = 0^o$, $h = 8'$

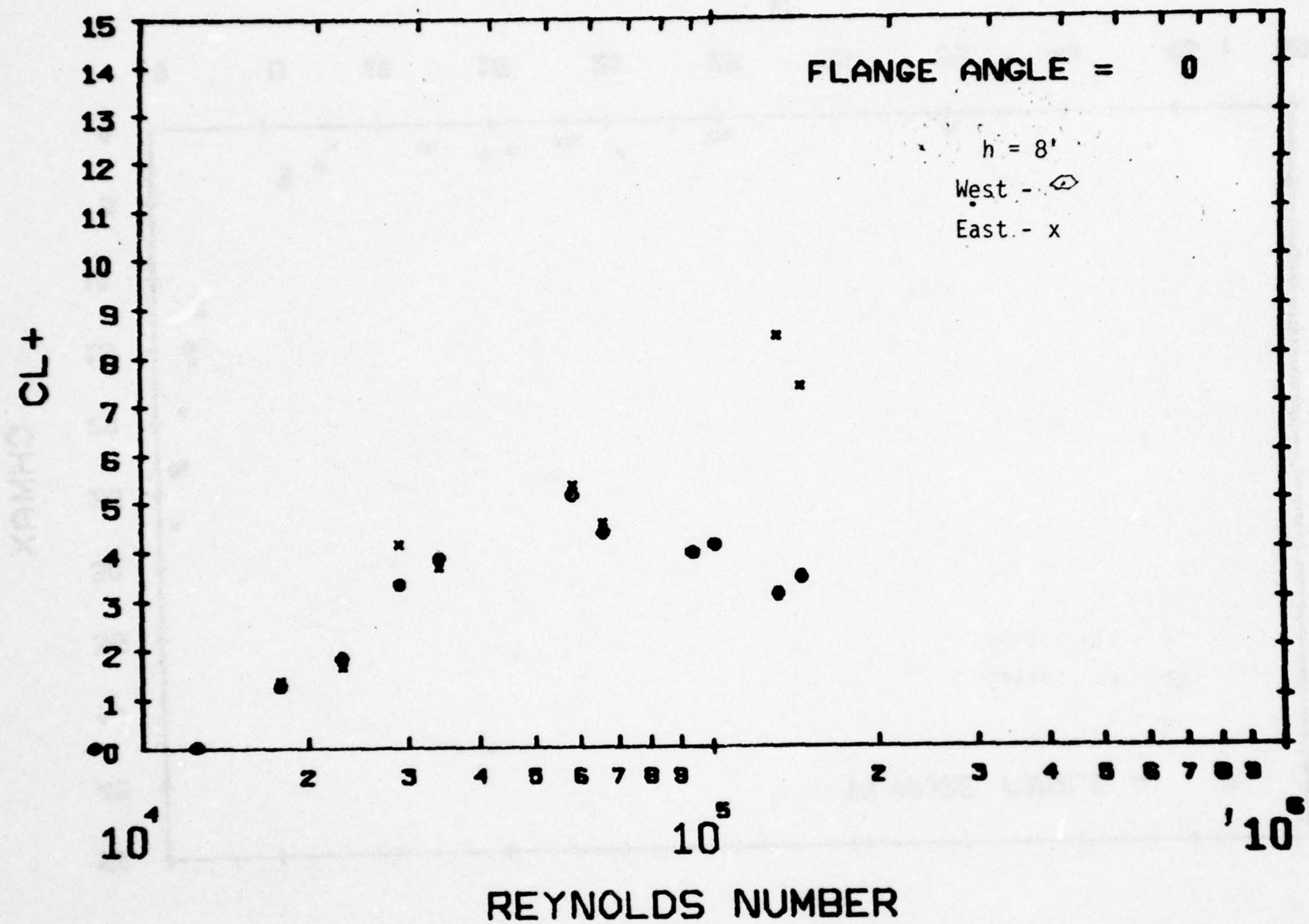

FIG. 20 - Comparison Between West Dynamometer and East Dynamometer for CDC vs. CL+ vs. Re, $\phi = 45^0$, h = 8'

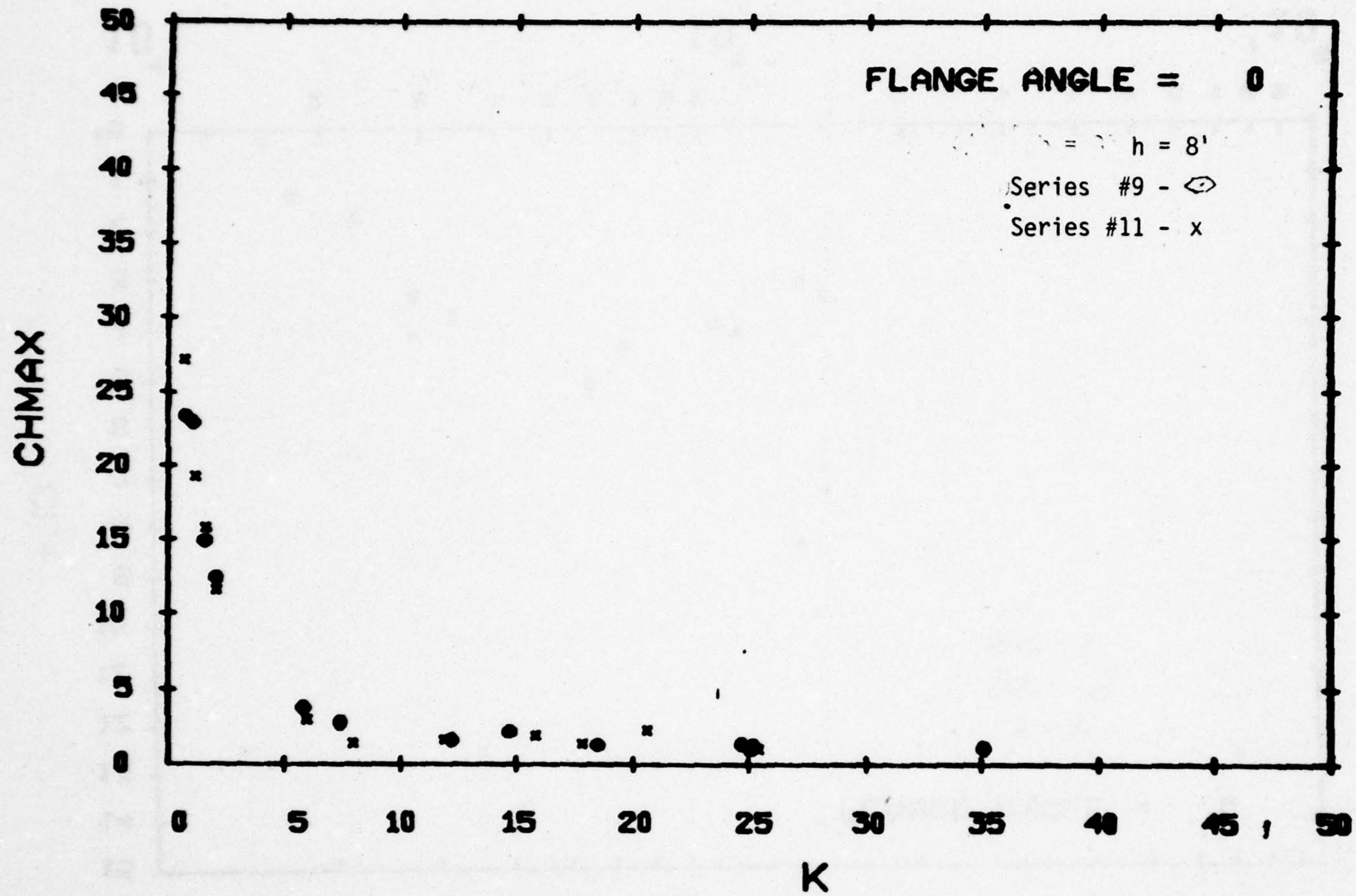

FIG. 21 - Comparison Between Repeated Tests, CHMAX vs. K, $\phi = 0^o$, h = 8'

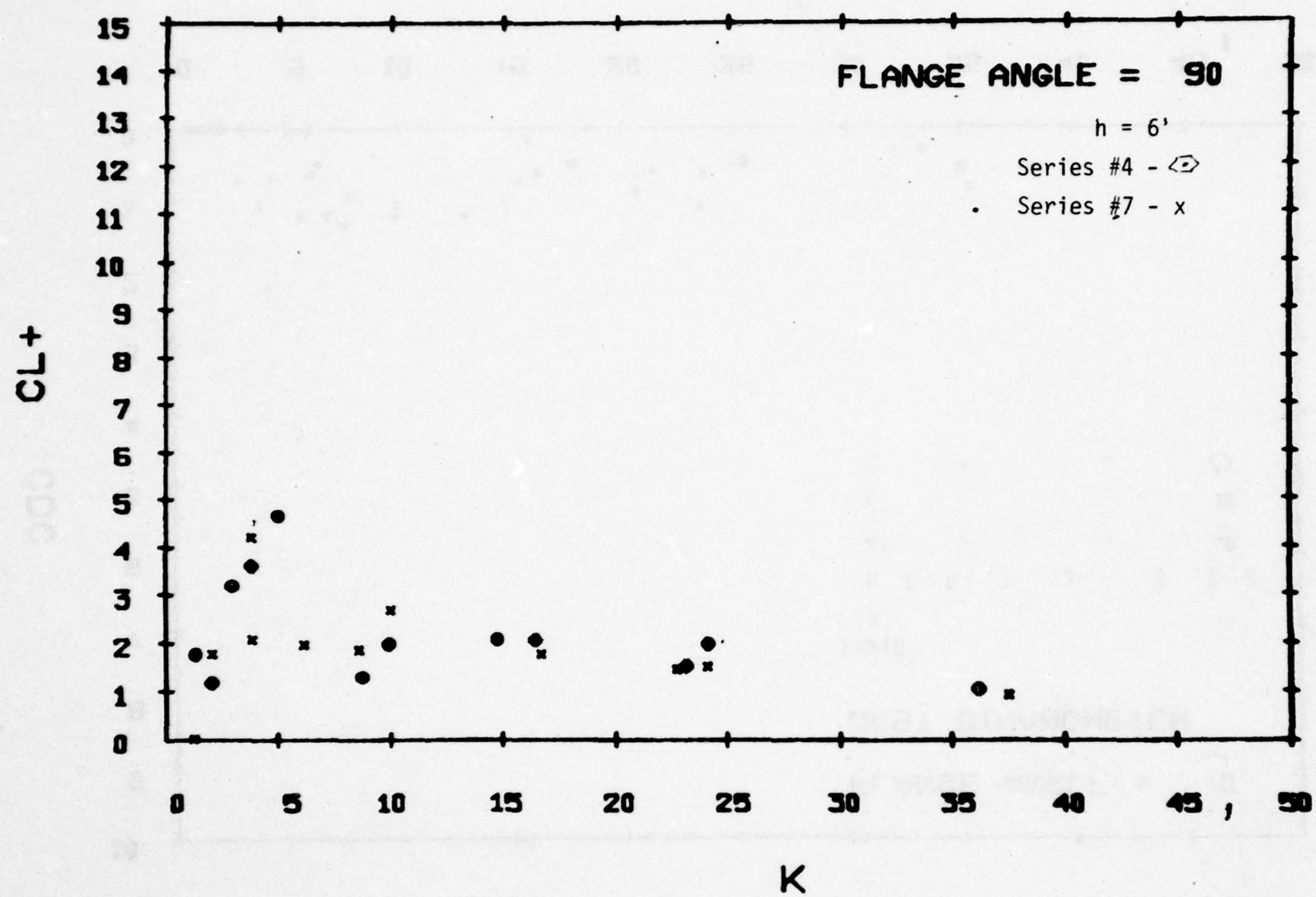

FIG. 22 - Comparison Between Repeated Tests, CL+ vs. K, $\phi = 90^0$, h = 6'

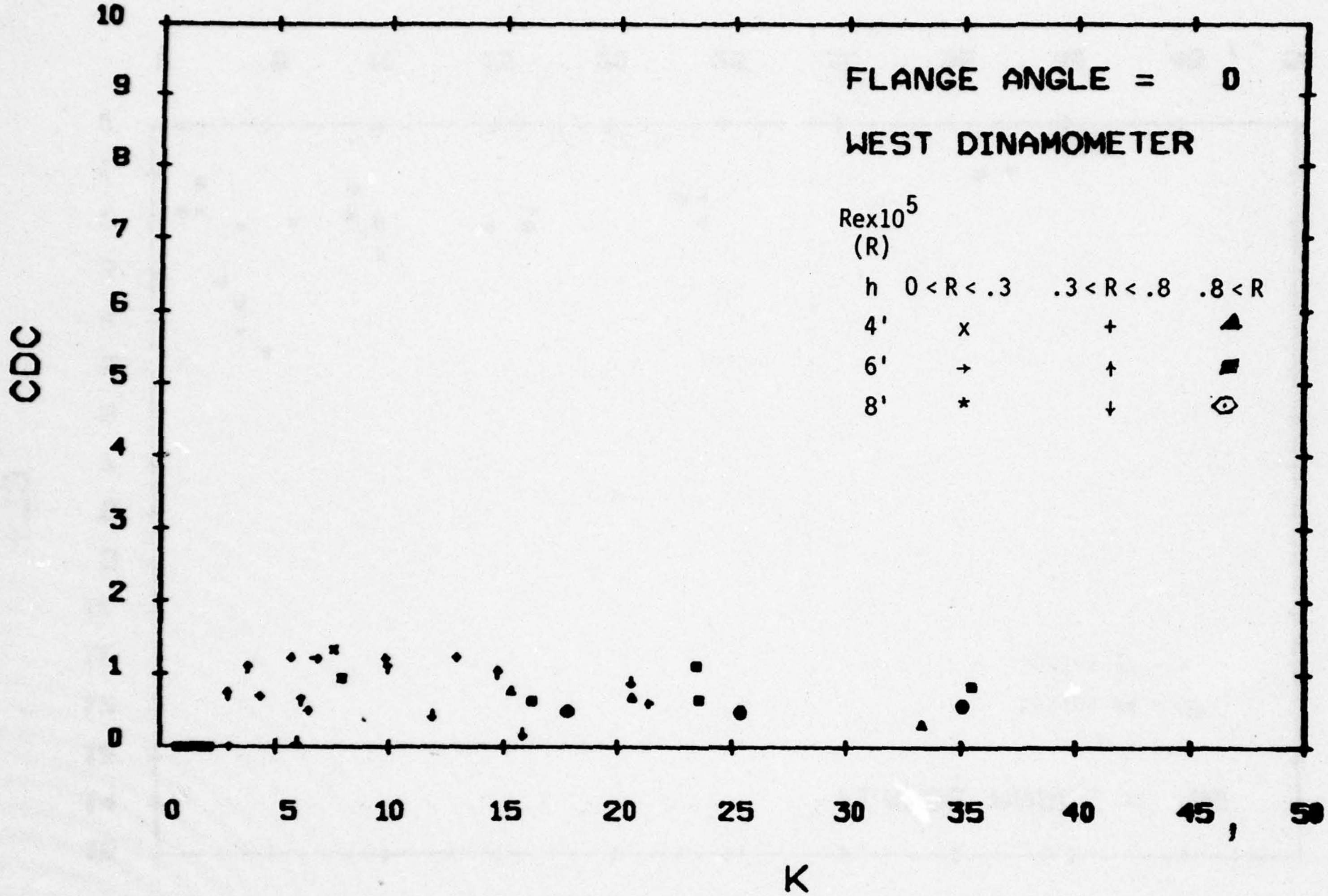

FIG. 23 - CDC vs. K for $\phi = 0^0$

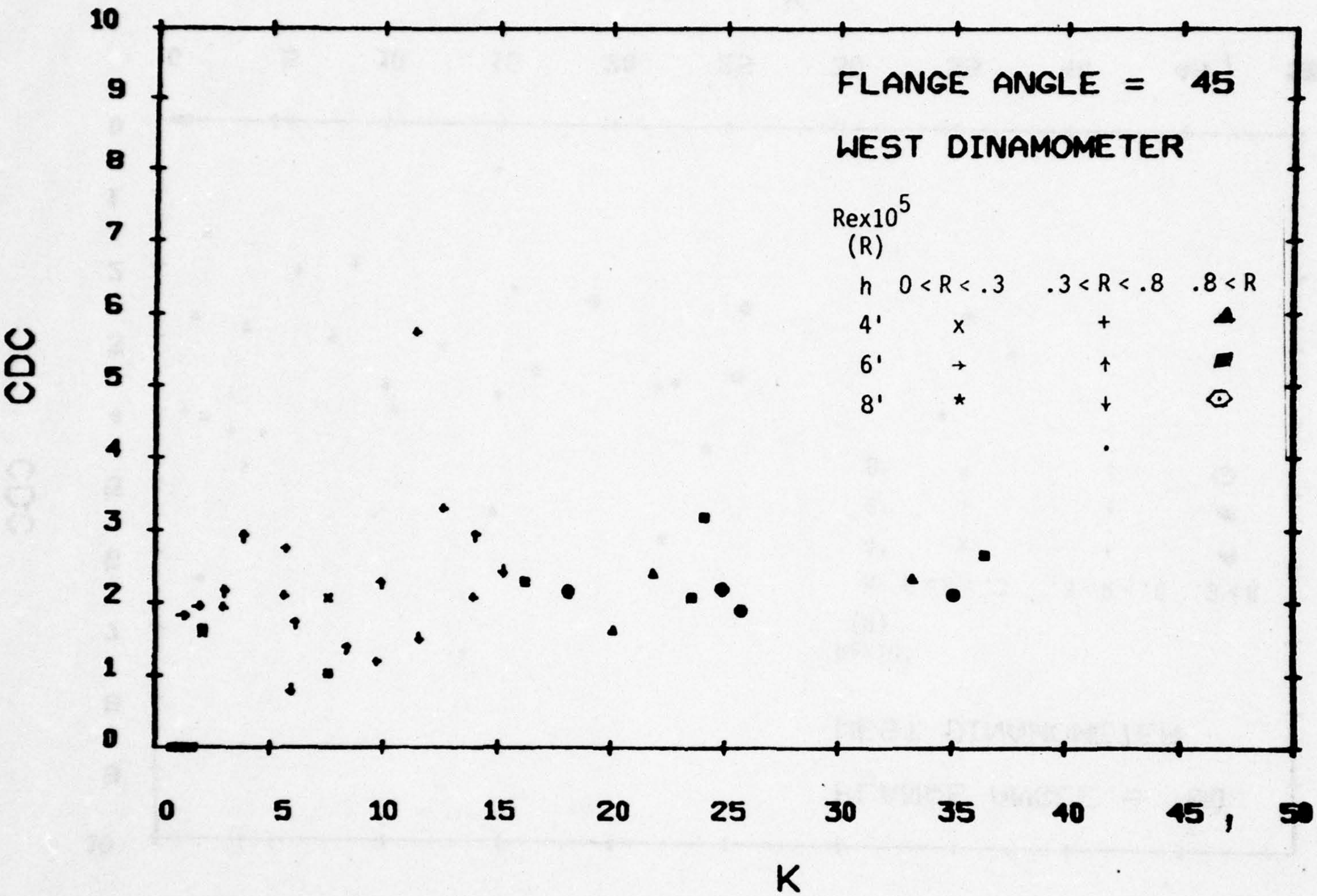

FIG. 24 - CDC vs. K for $\phi = 45^0$

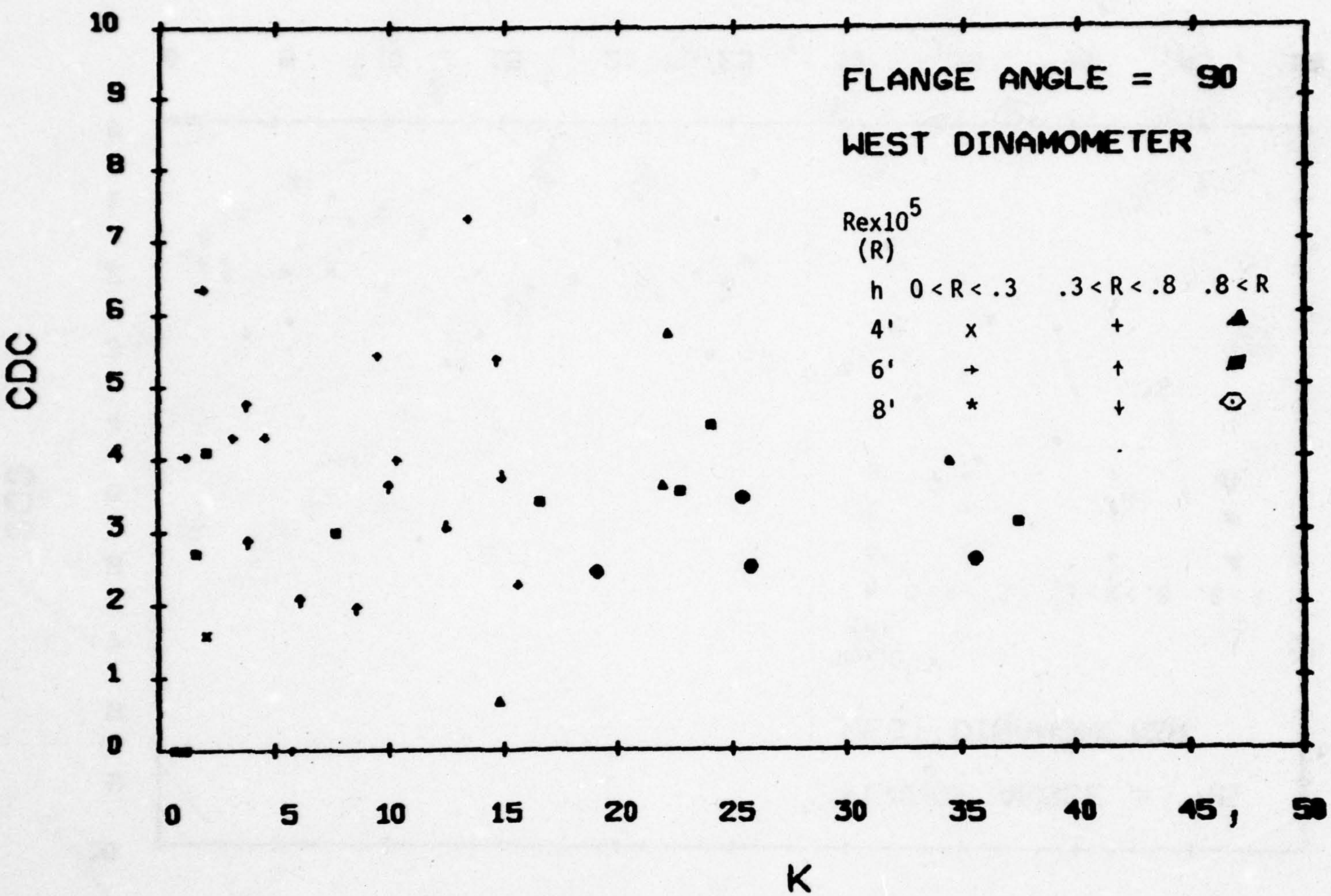

FIG. 25 - CDC vs. K for $\phi = 90^0$

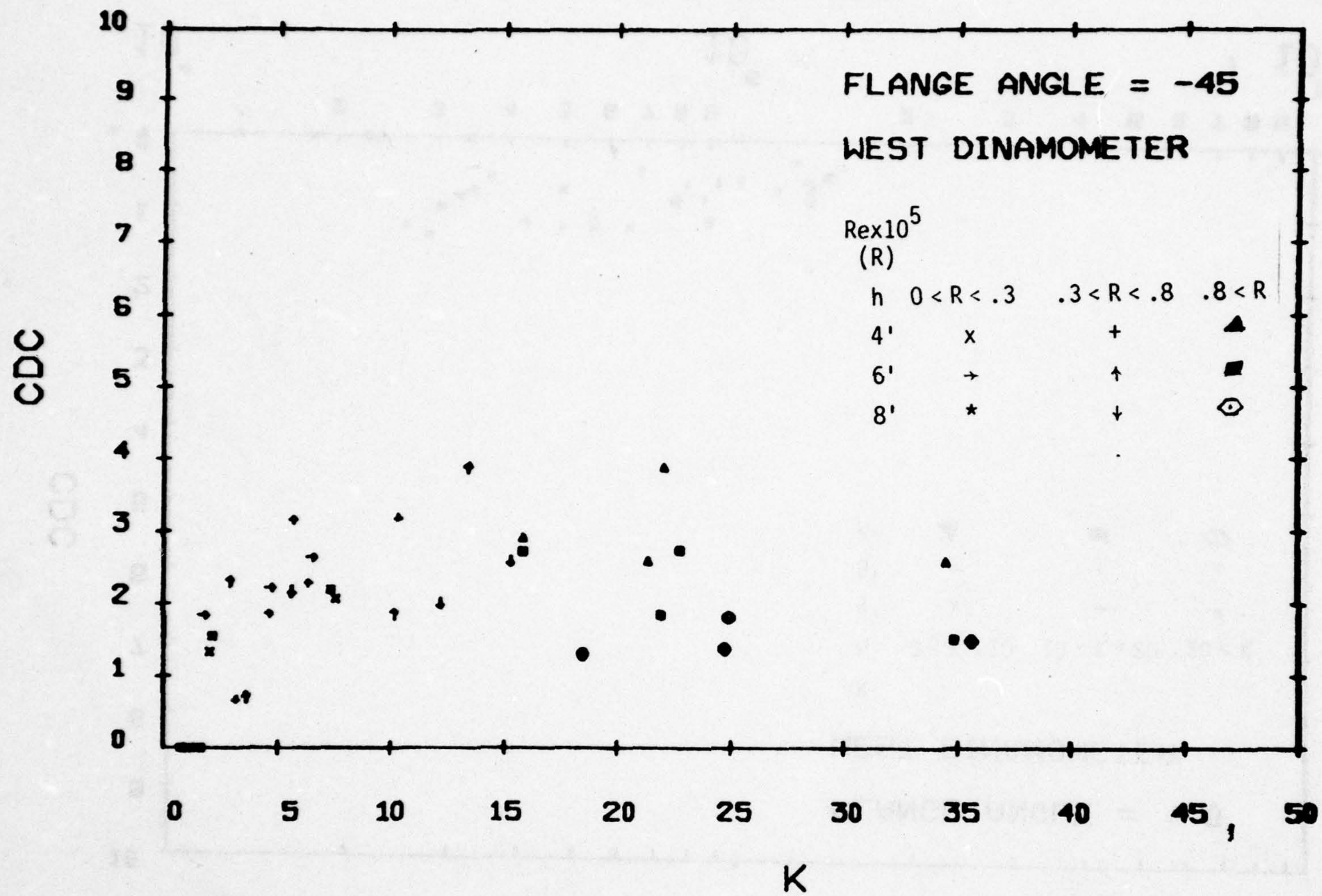

FIG. 26 - CDC vs. K for ϕ = -45^{0}

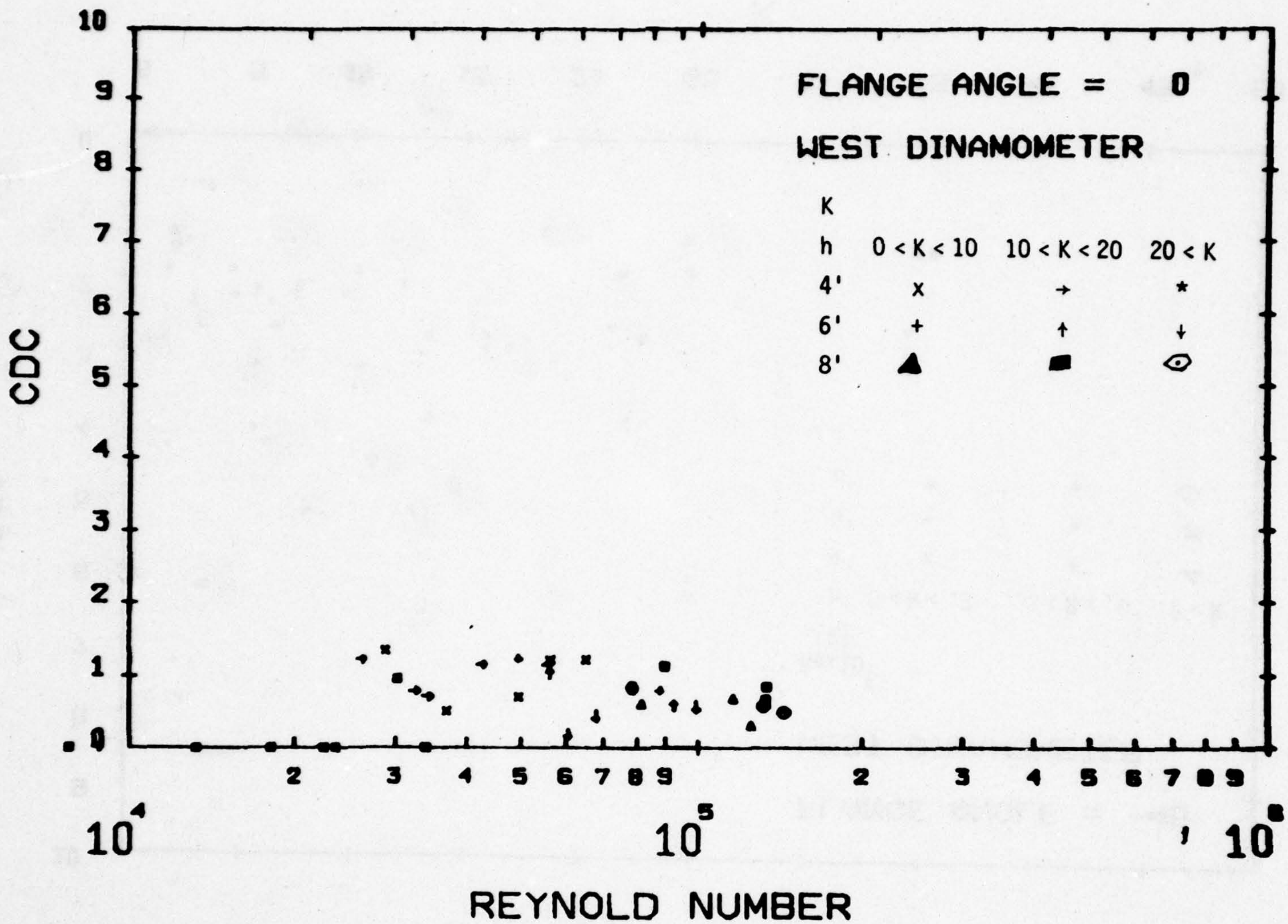

FIG. 27 - CDC vs. Re for $\phi = 0^{o}$

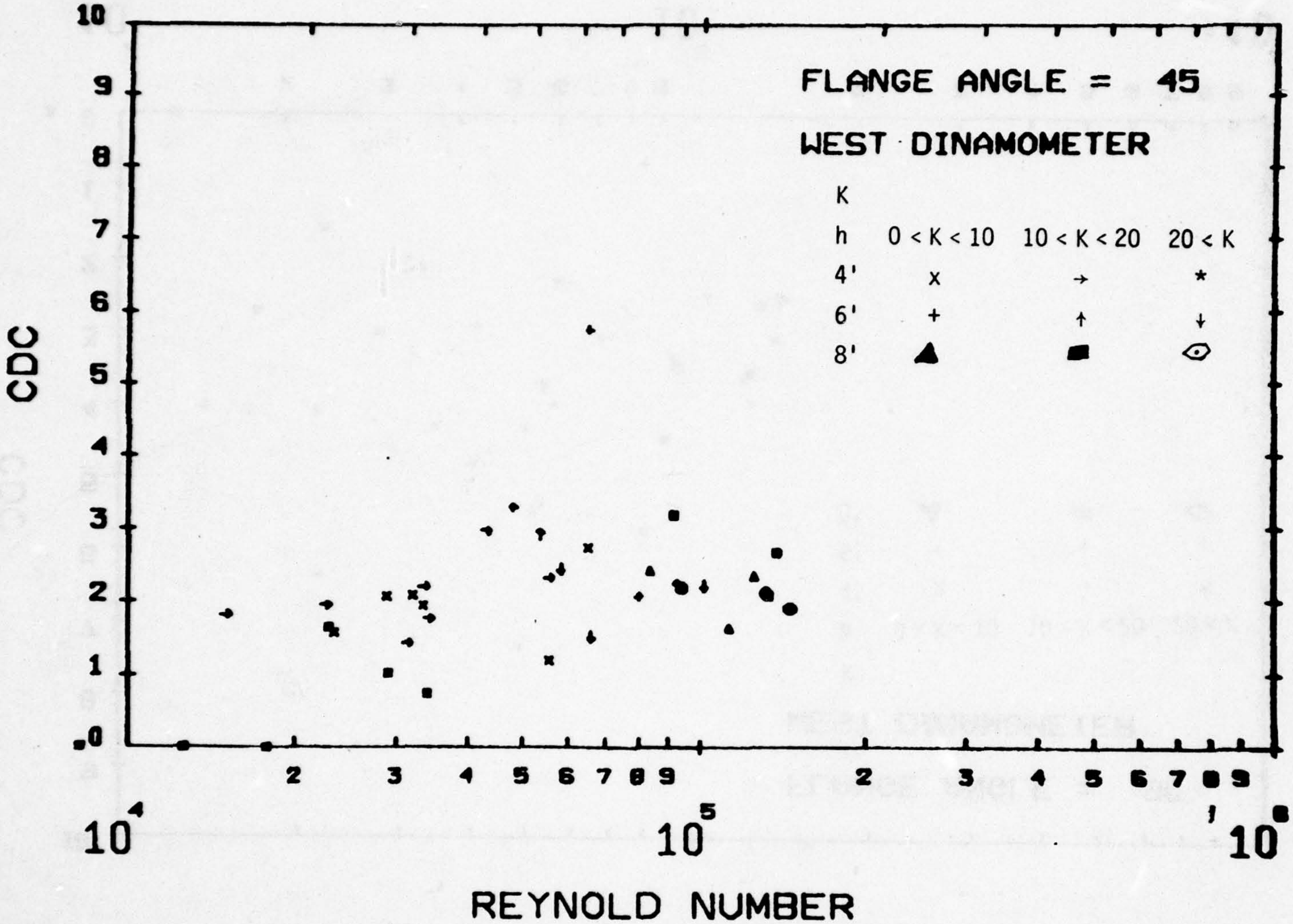

FIG. 28 - CDC vs. Re. for $\phi = 45^{0}$

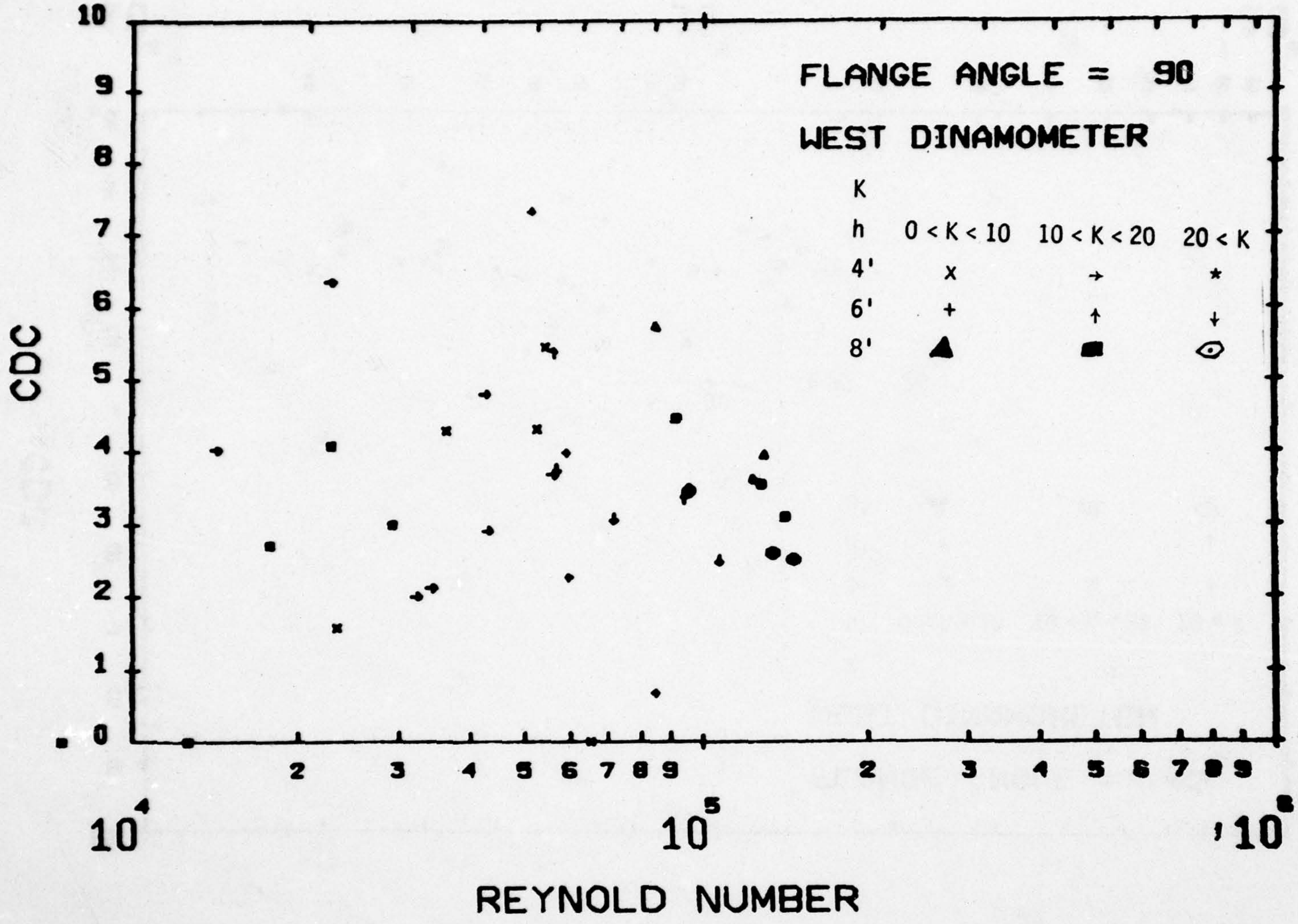

FIG. 29 - CDC vs. Re for $\phi = 90^0$

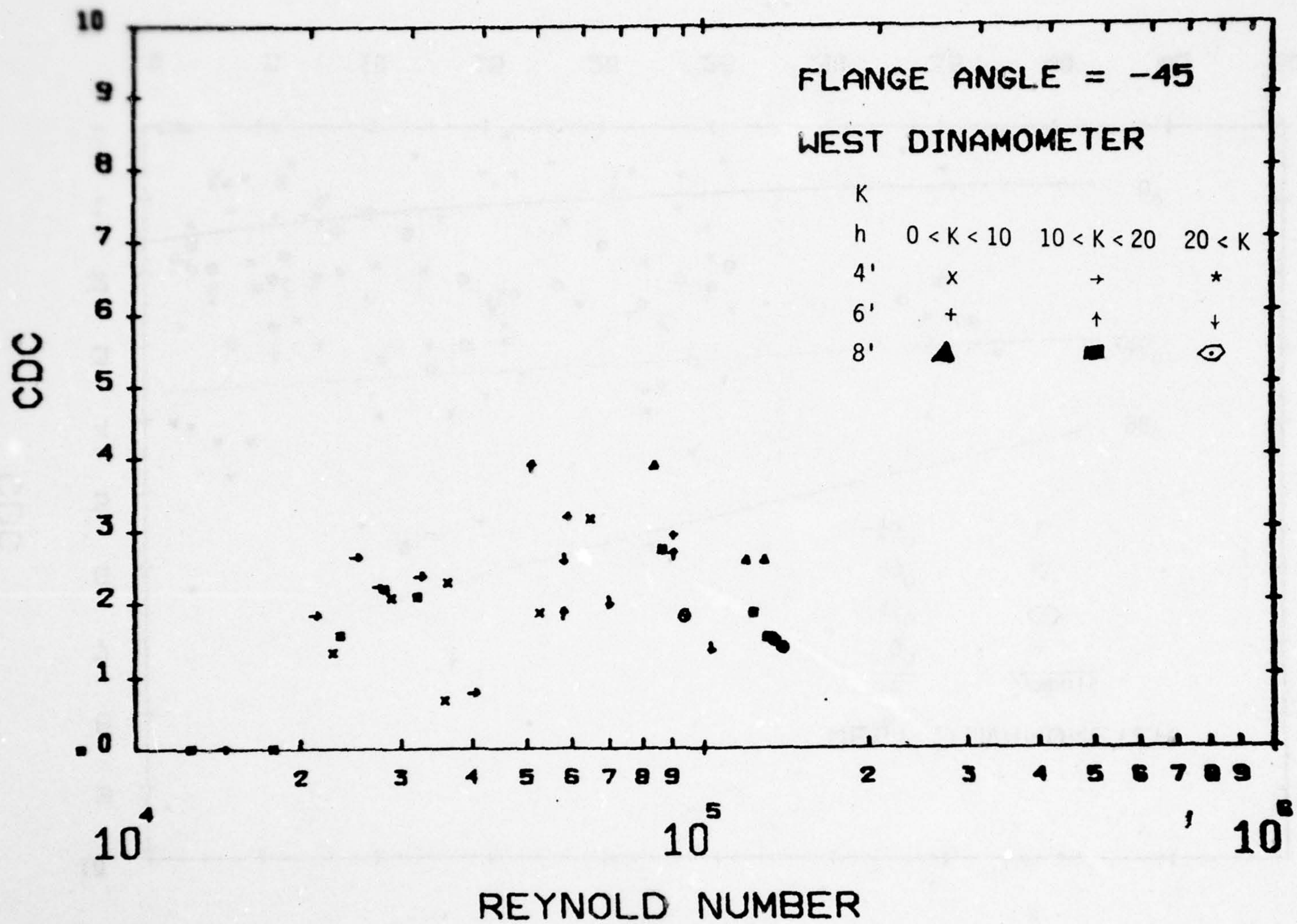

FIG. 30 - CDC vs. Re for $\phi = -45^{0}$

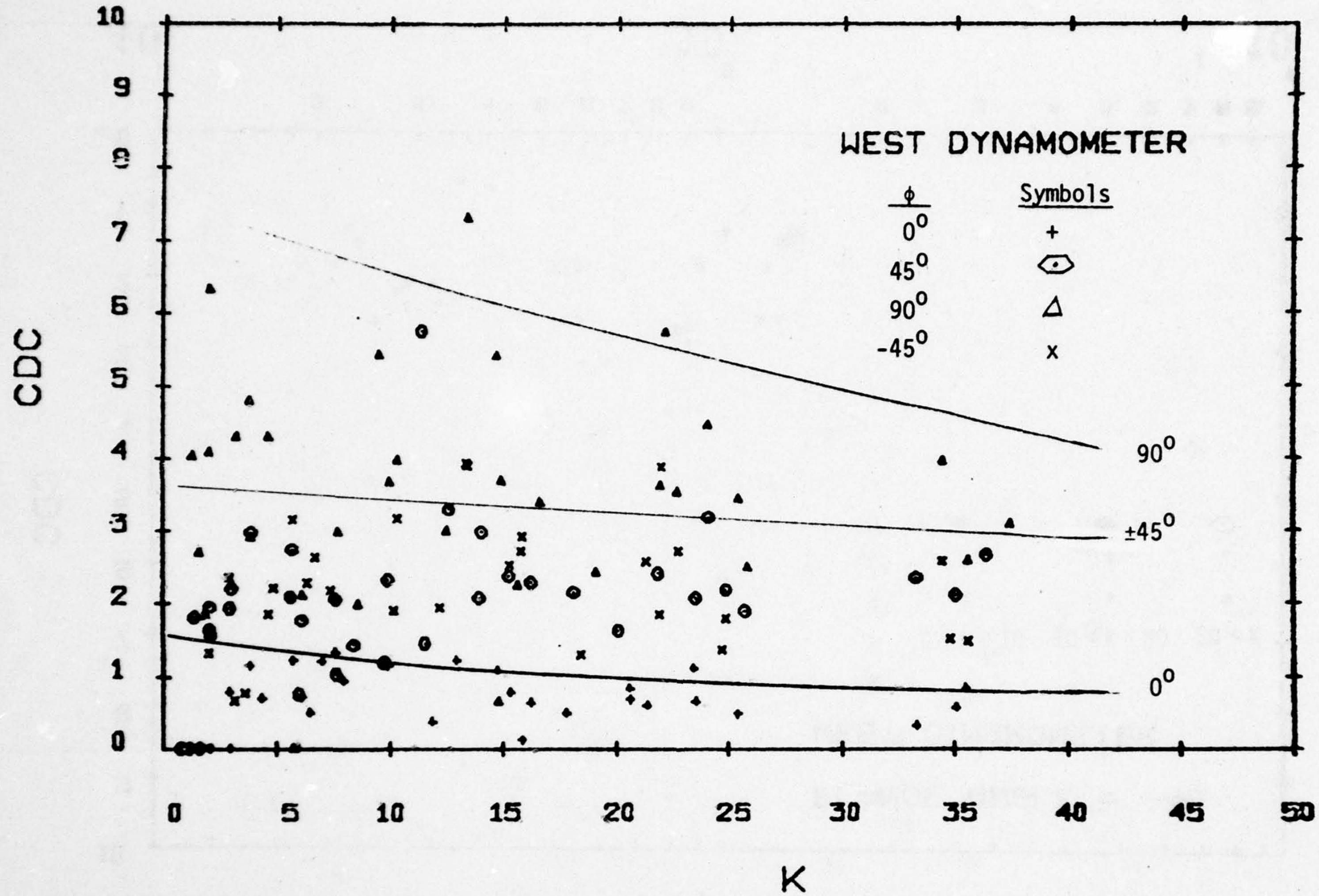

FIG. 31 - CDC vs. K for all ϕs

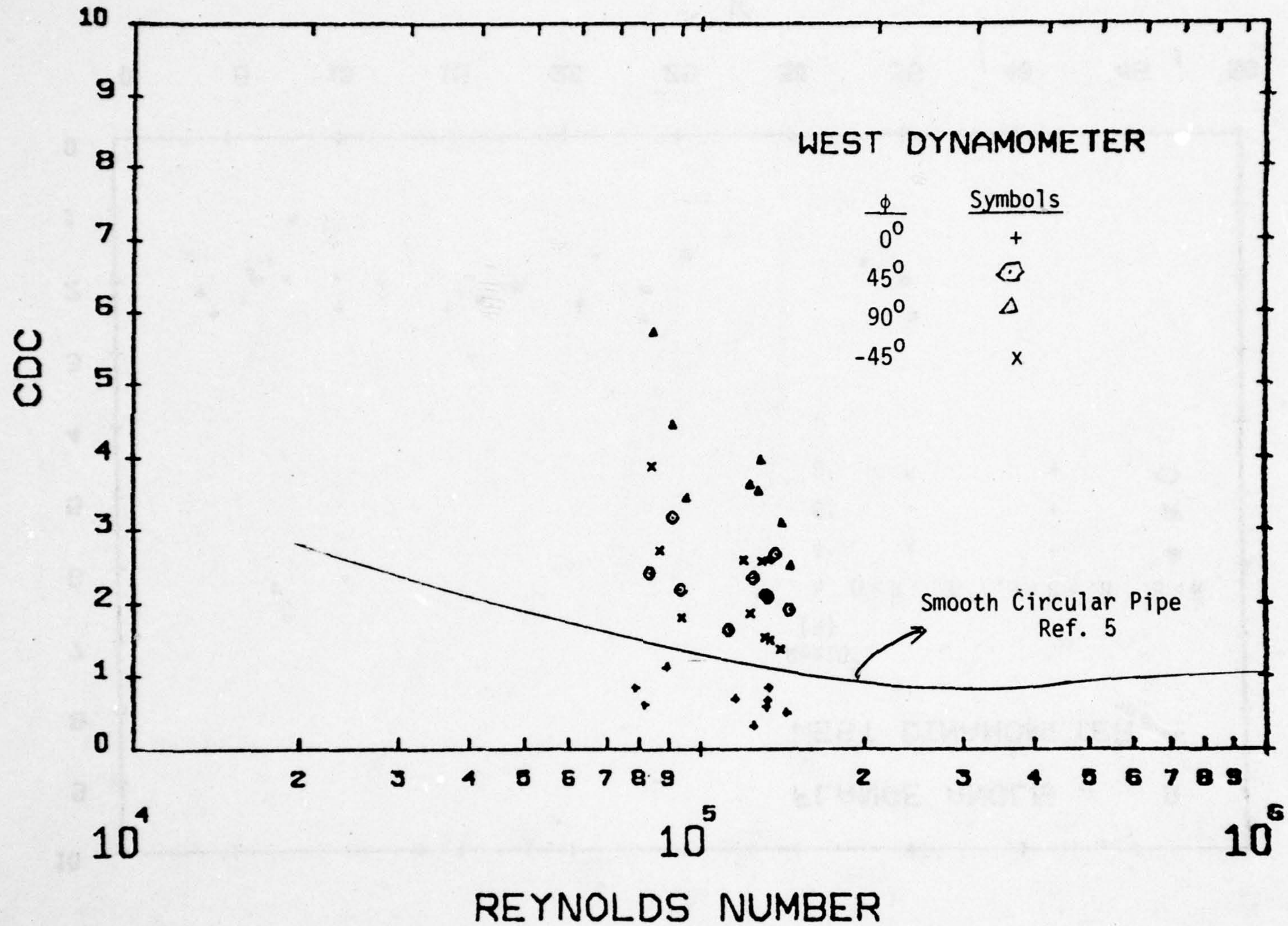

FIG. 32 - CDC vs. Re for all ϕs, K >20

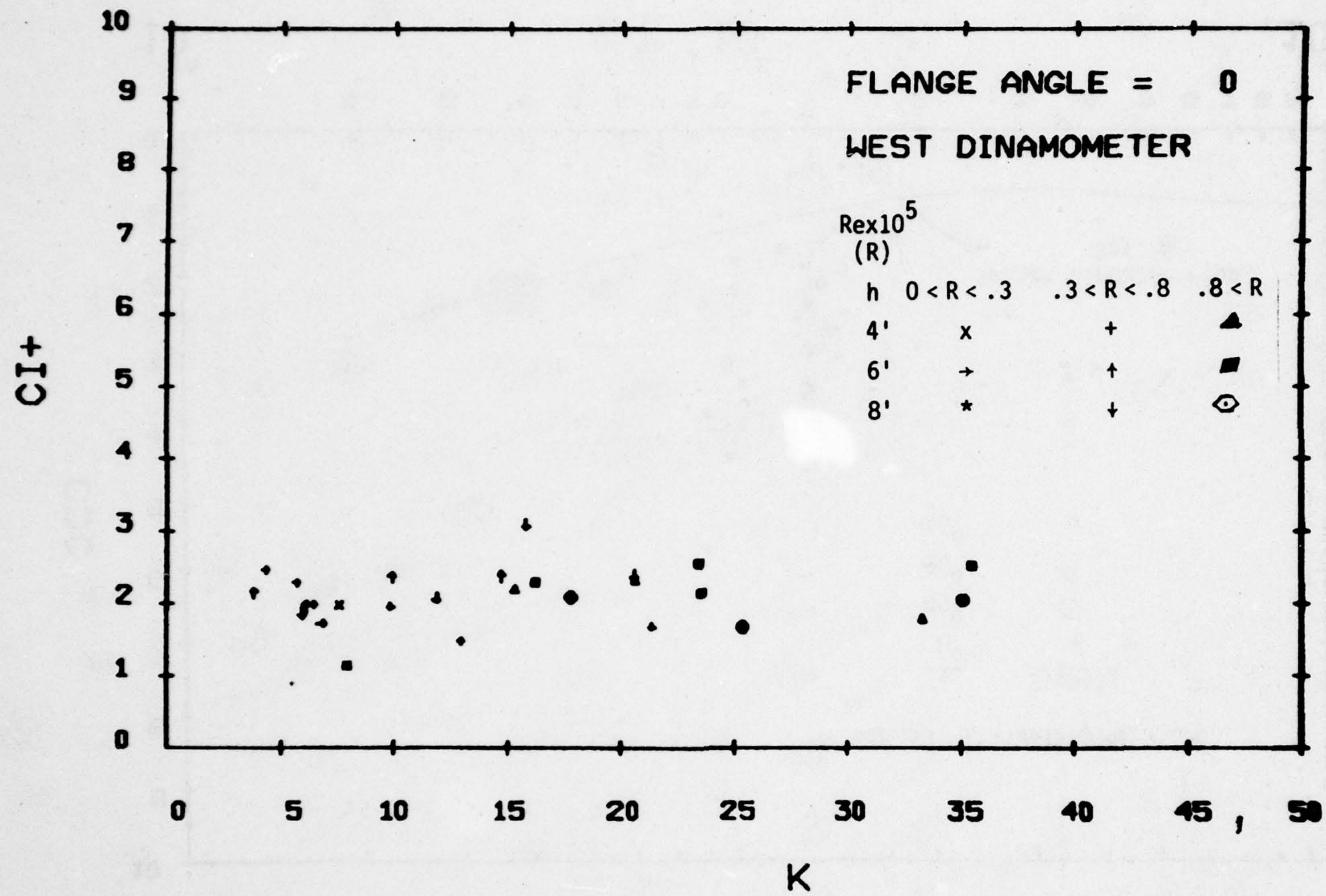

FIG. 33 - CI+ vs. K for $\phi = 0^0$

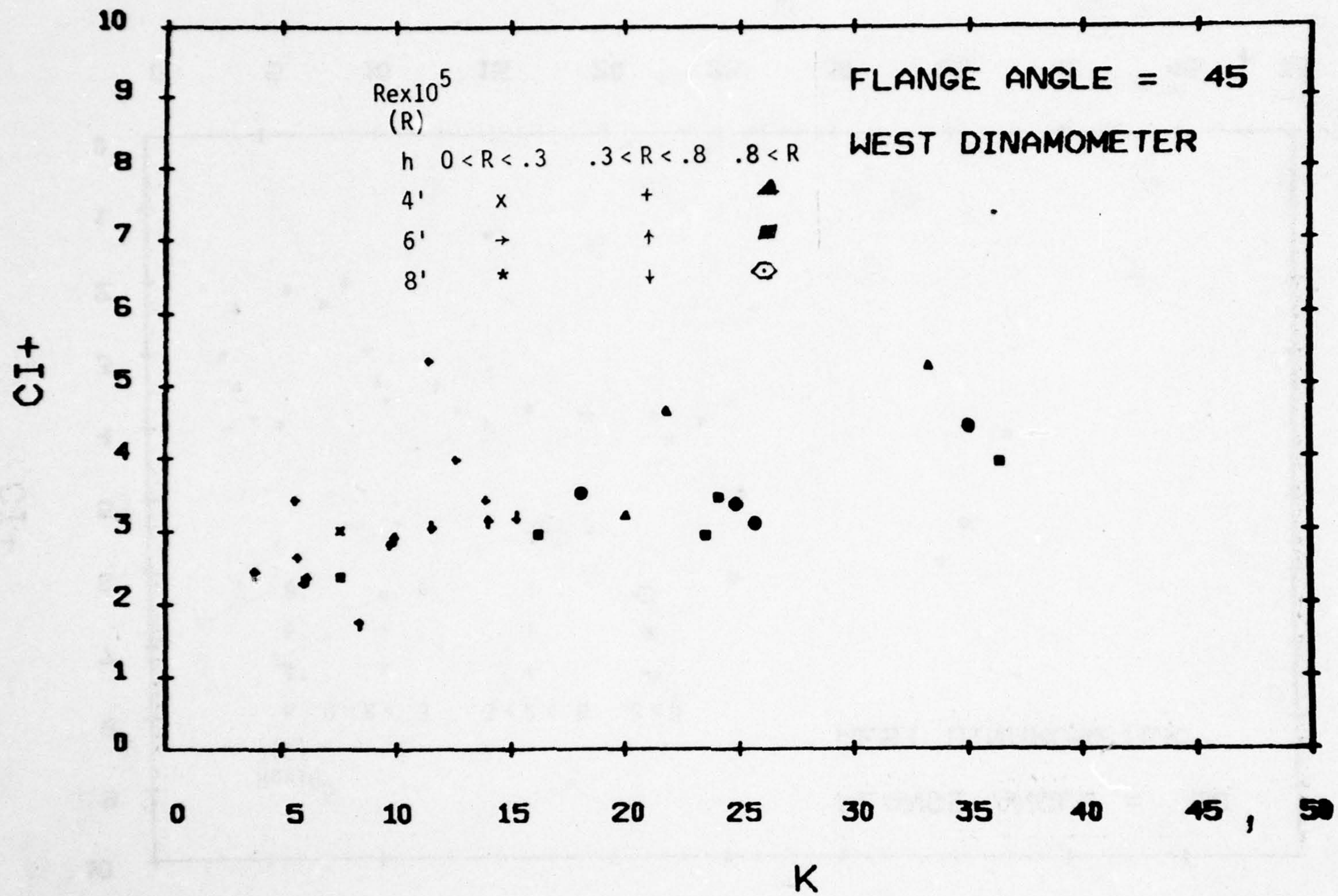

FIG. 34 - CI+ vs. K for $\phi = 45^{0}$

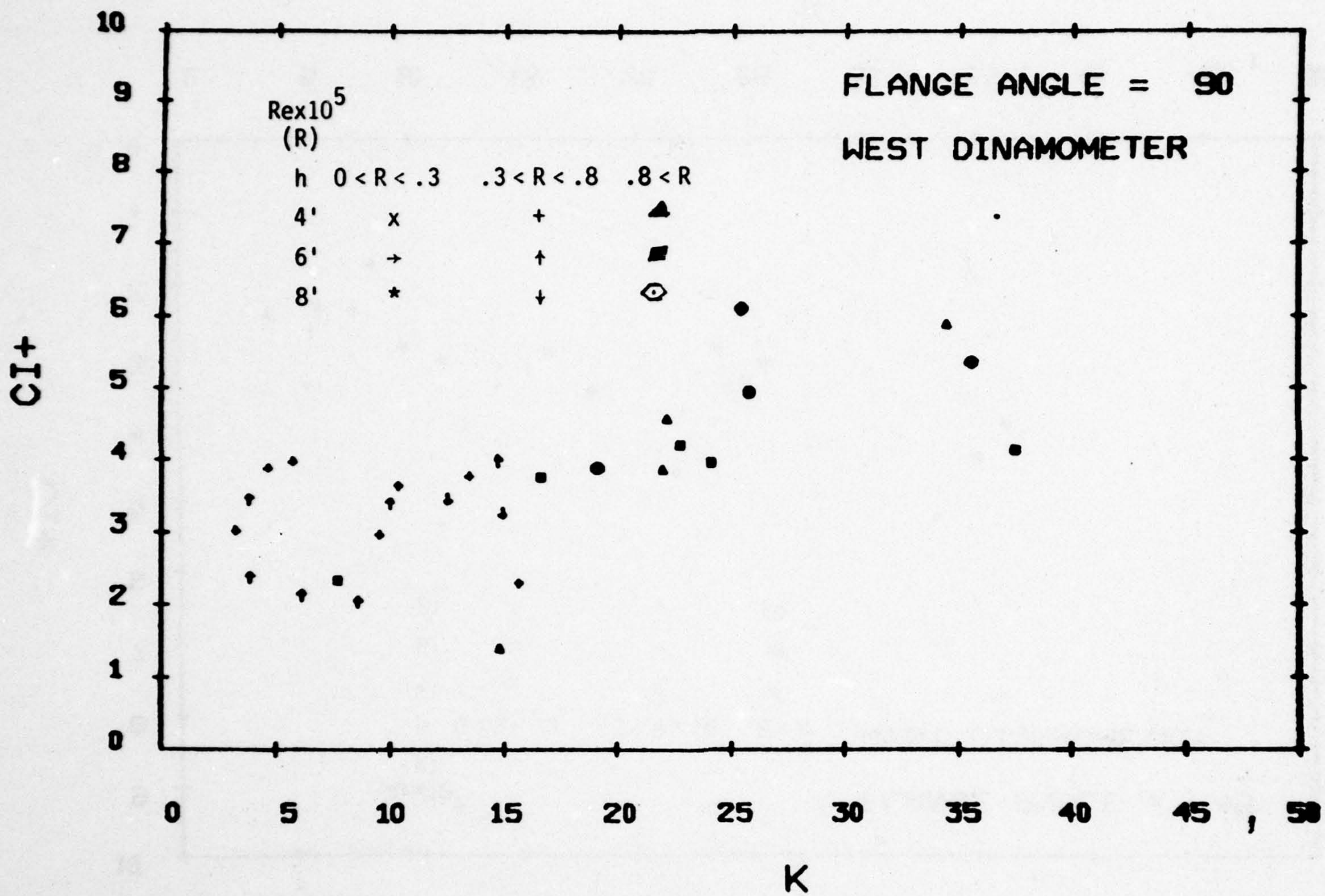

FIG. 35 - CI+ vs. K for $\phi = 90^0$

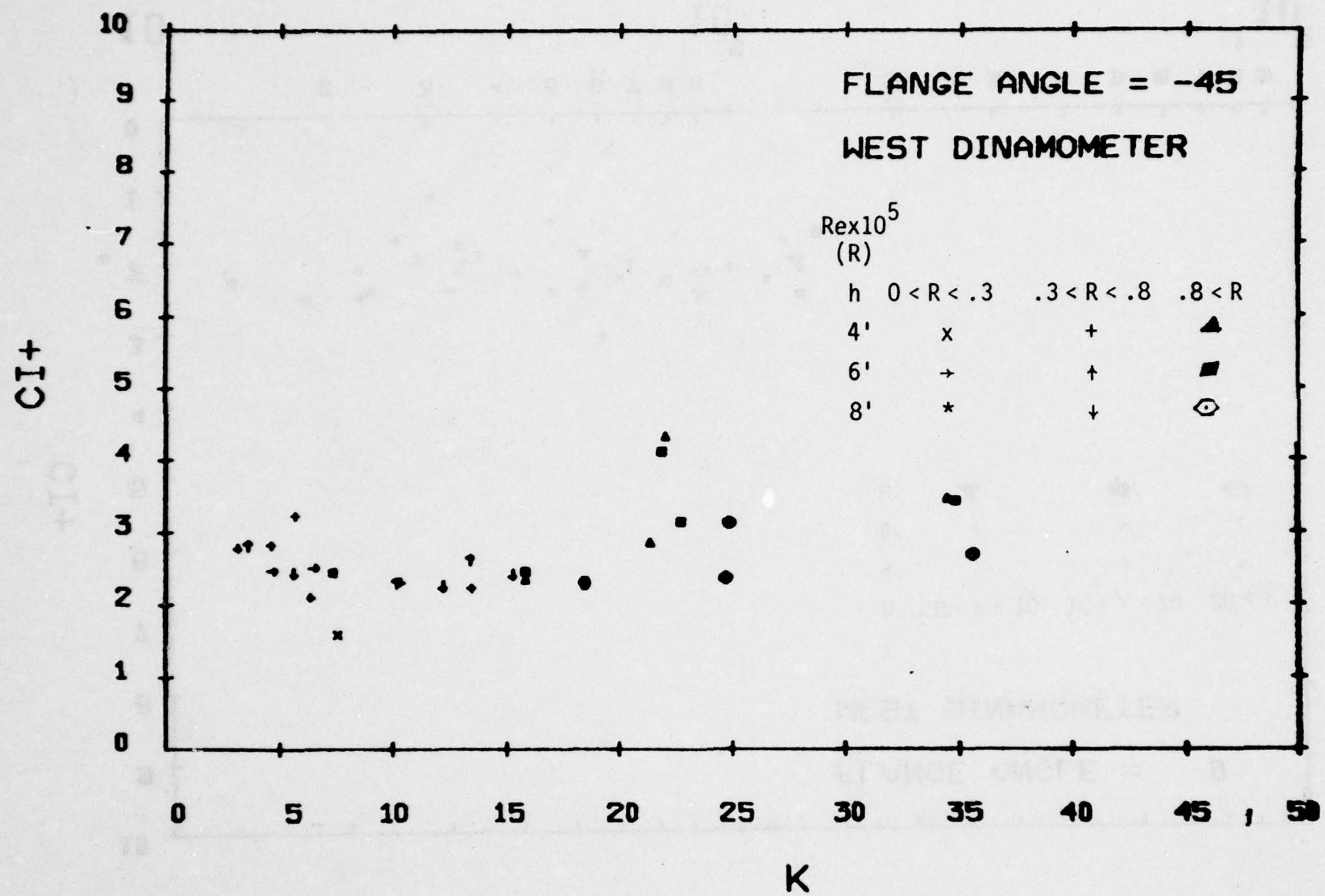

FIG. 36 - CI+ vs. K for $\phi = -45^0$

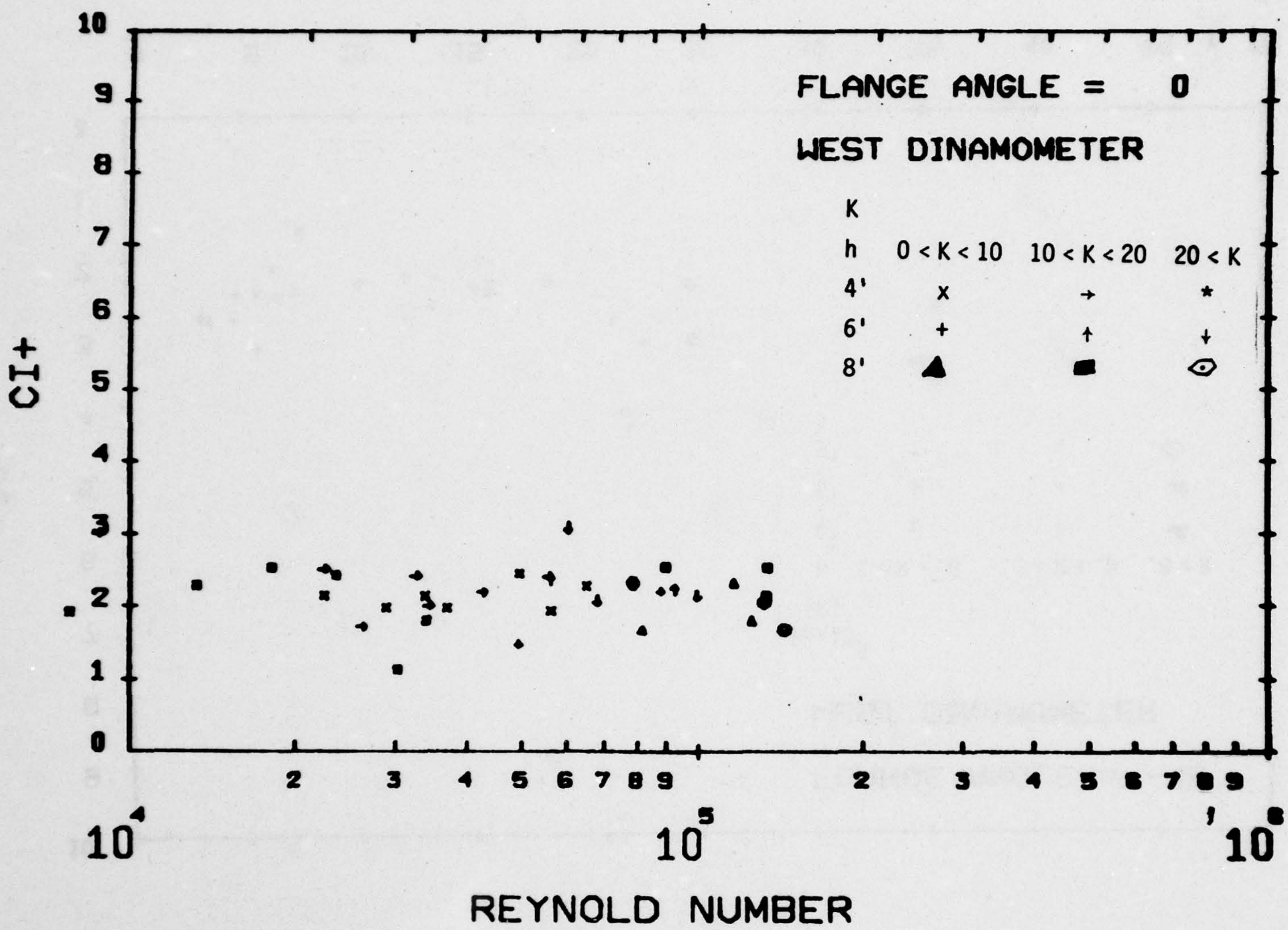

FIG. 37 - CI+ vs. Re for $\phi = 0^0$

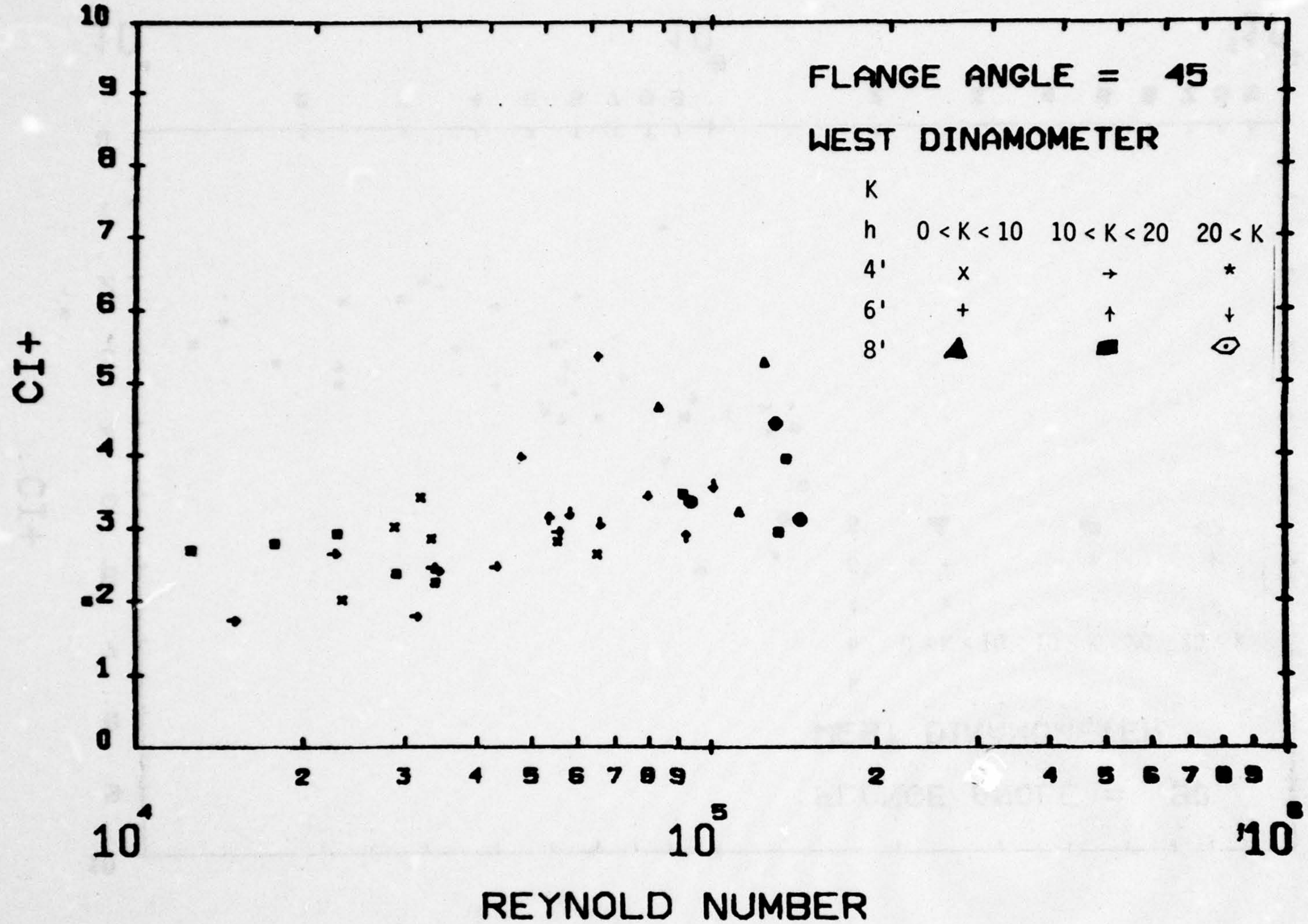

FIG. 38 - CI+ vs. Re for $\phi = 45^0$

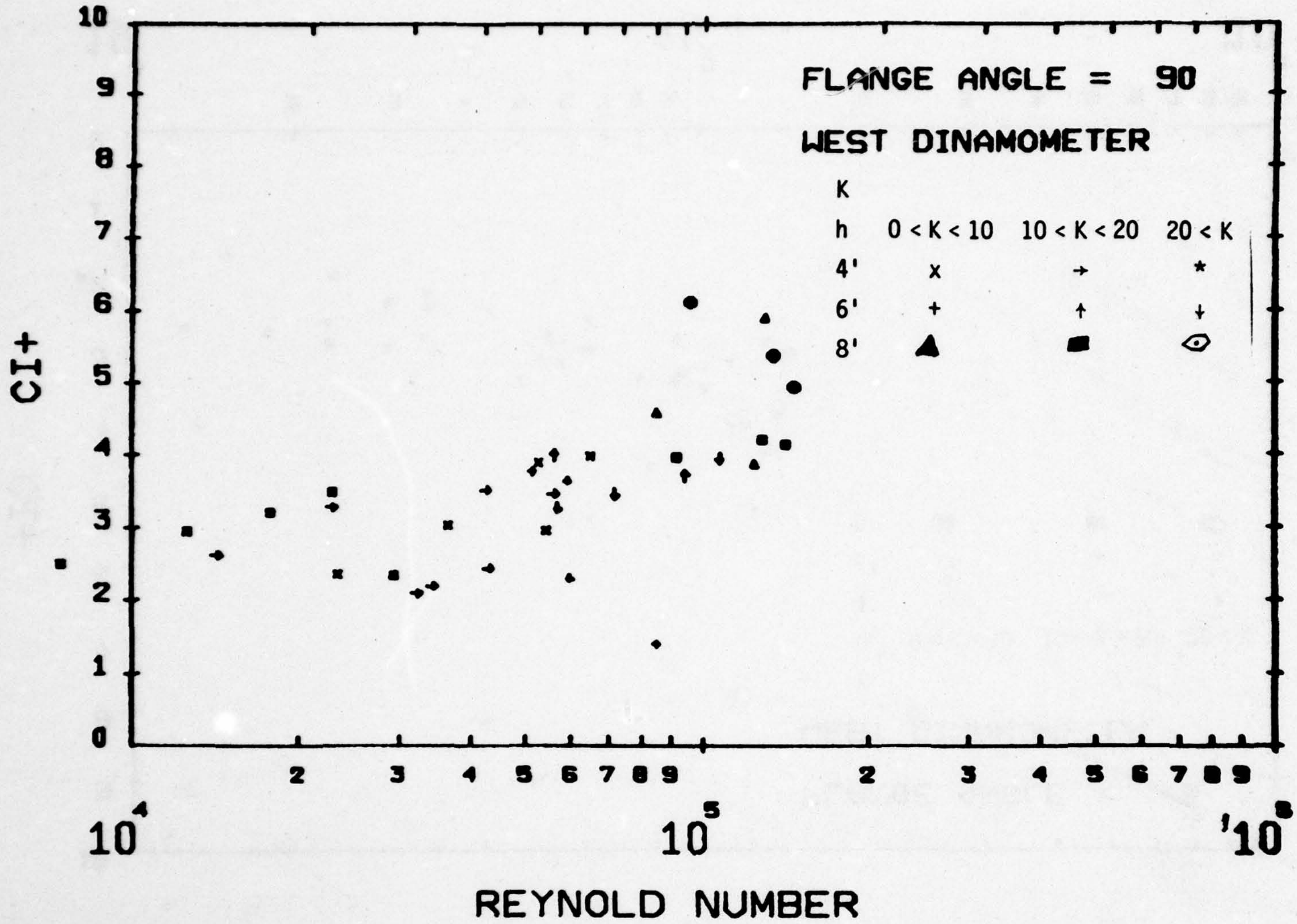

FIG. 39 - CI+ vs. Re for $\phi = 90^0$

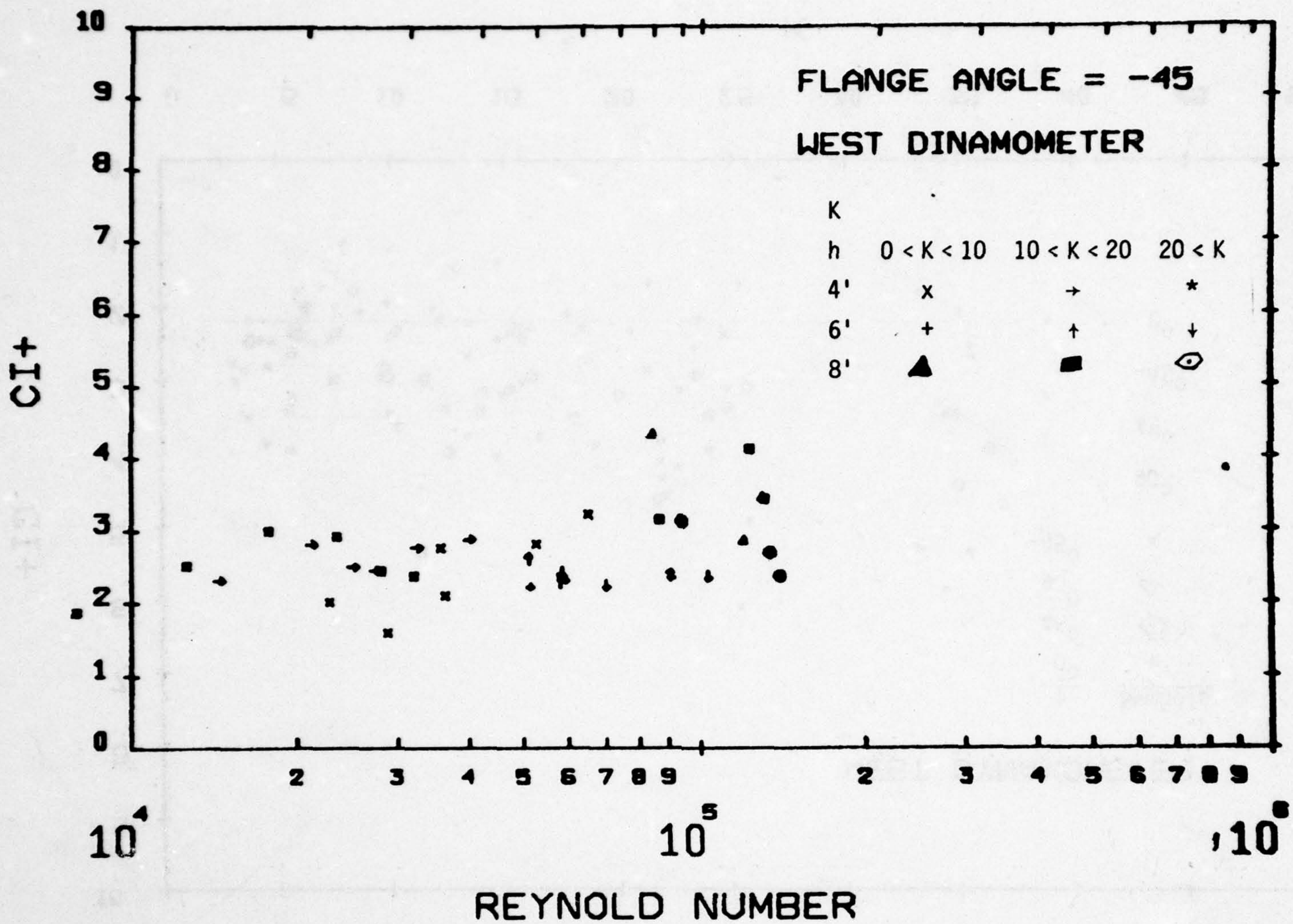

FIG. 40 - CI+ vs. Re for $\phi = -45^0$

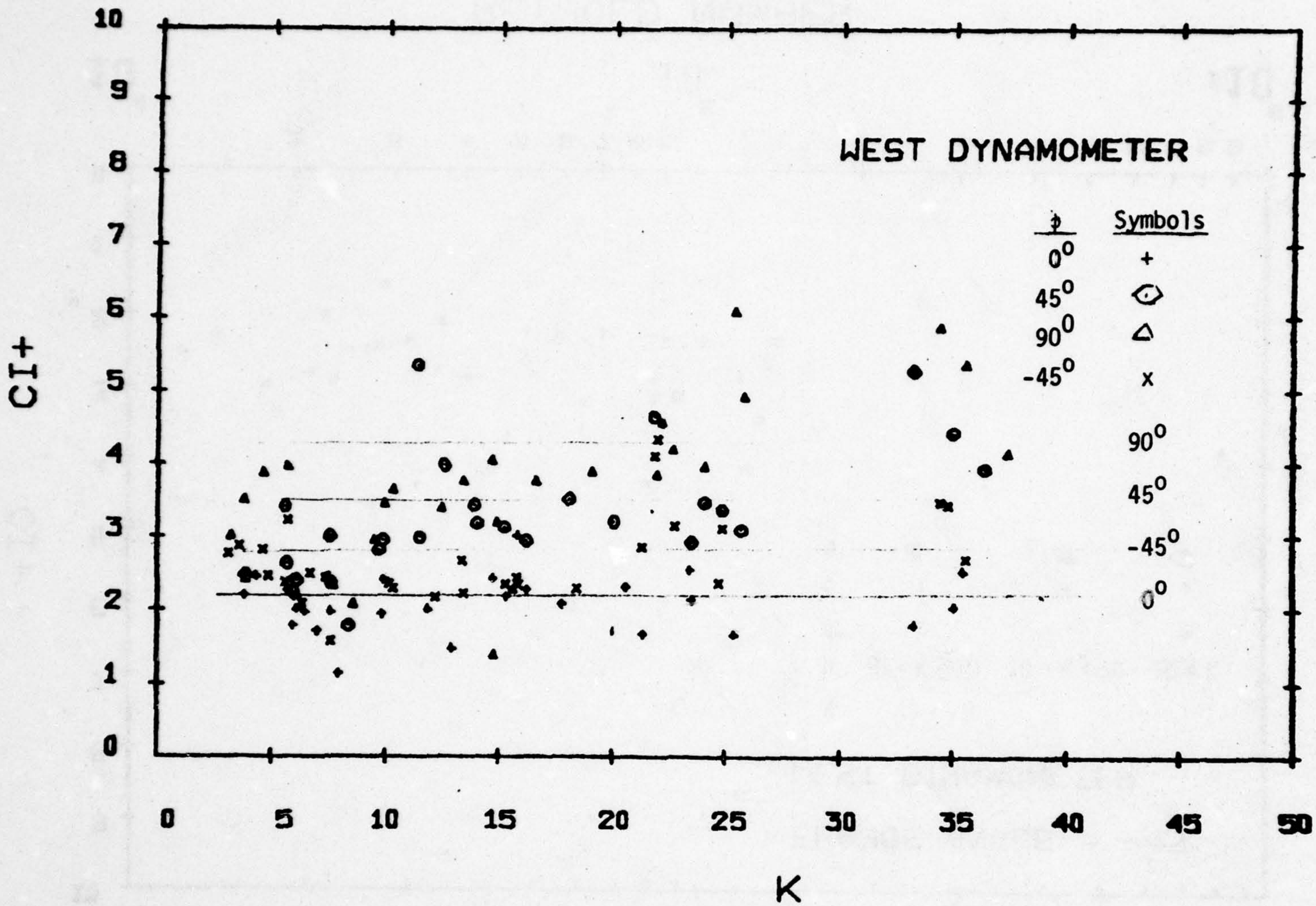

FIG. 41 - CI+ vs. K for all ϕs

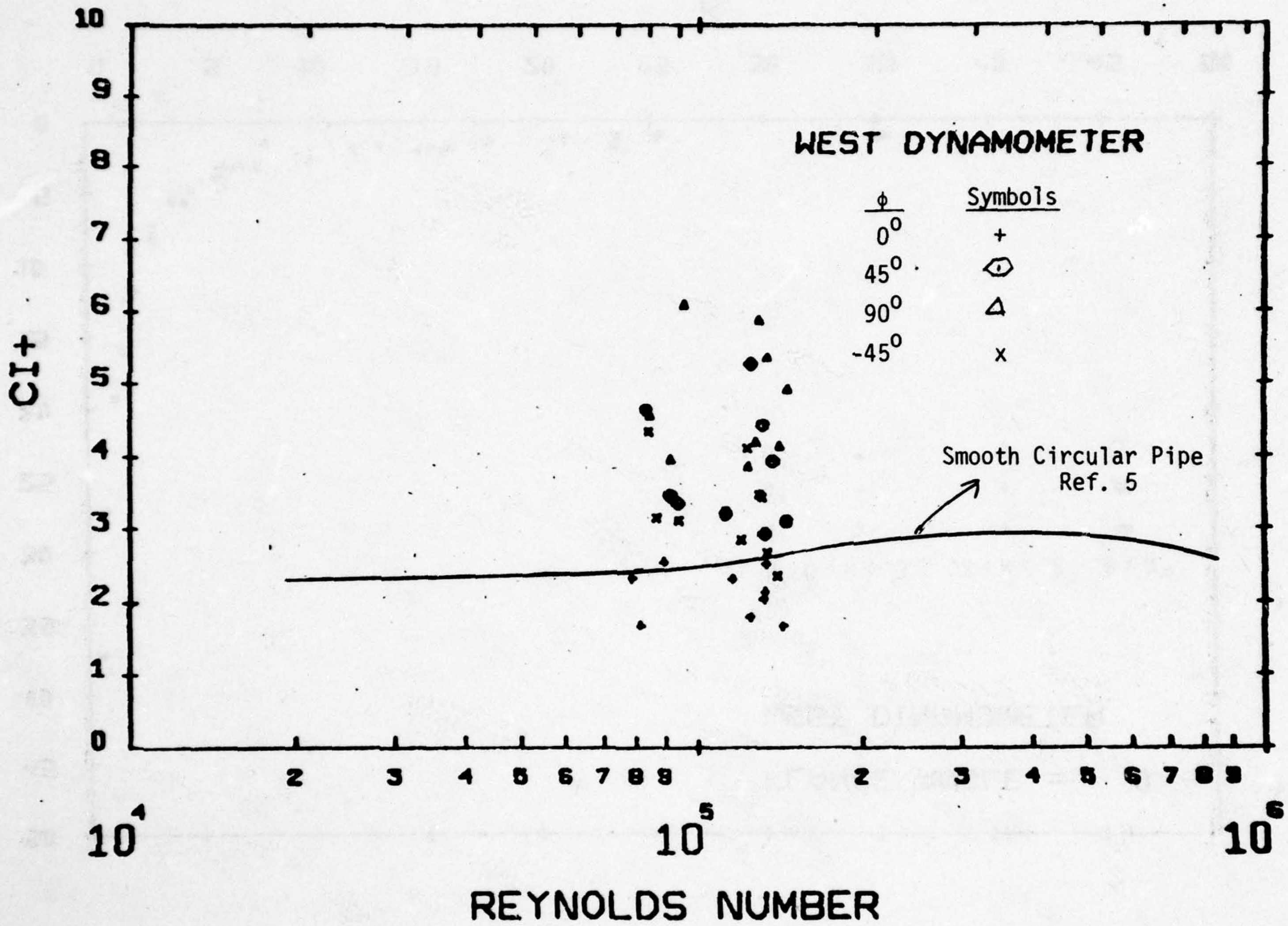

FIG. 42 - CI+ vs. Re for all ϕs, K >20

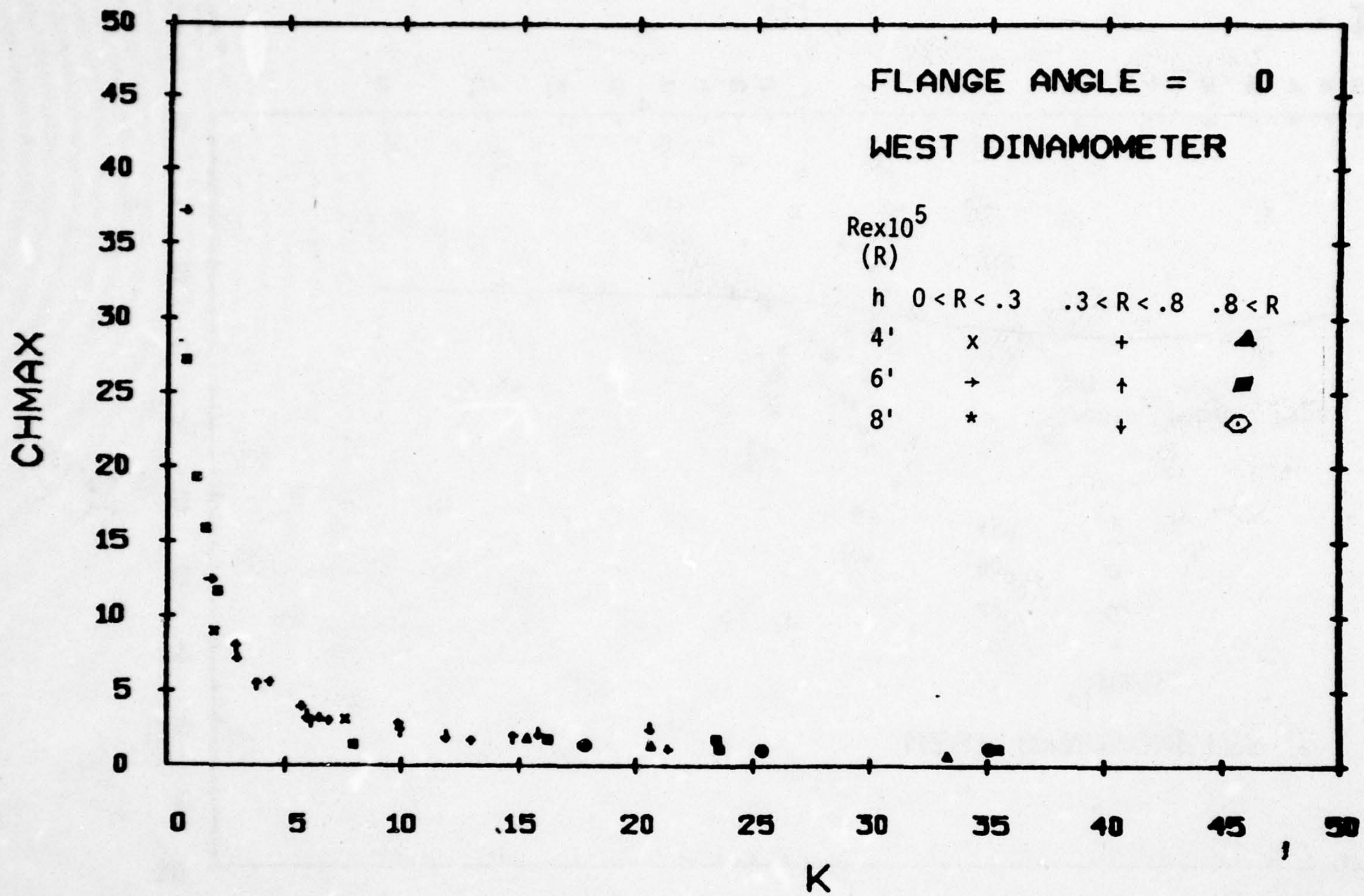

FIG. 43 - CHMAX vs. K for $\phi = 0^{0}$

AD-A055 623 OREGON STATE UNIV CORVALLIS WAVE RESEARCH FACILITY F/G 13/11
ENGINEERING REPORT ON WAVE TANK TESTS ON SPLIT PIPE.(U)
DEC 77 T YAMAMOTO N68305-77-C-0041
UNCLASSIFIED TR-3 CEL-CR-78.007 NL

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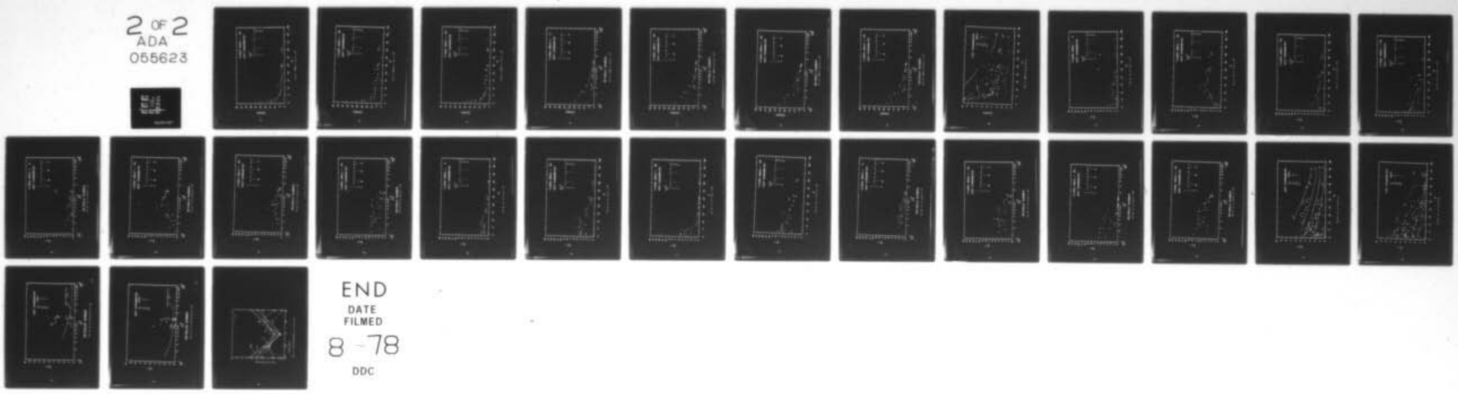

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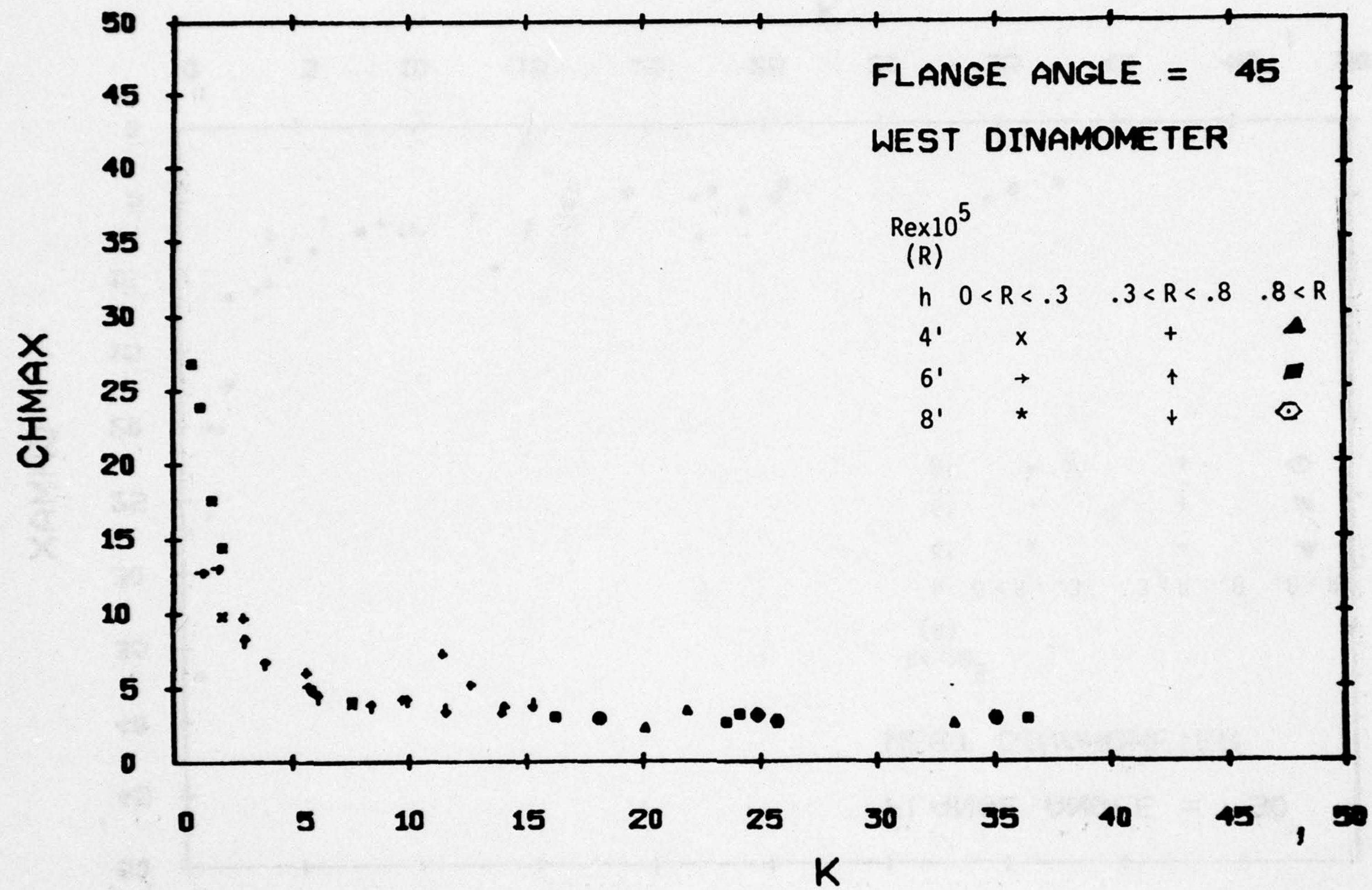

FIG. 44 - CHMAX vs. K for $\phi = 45^0$

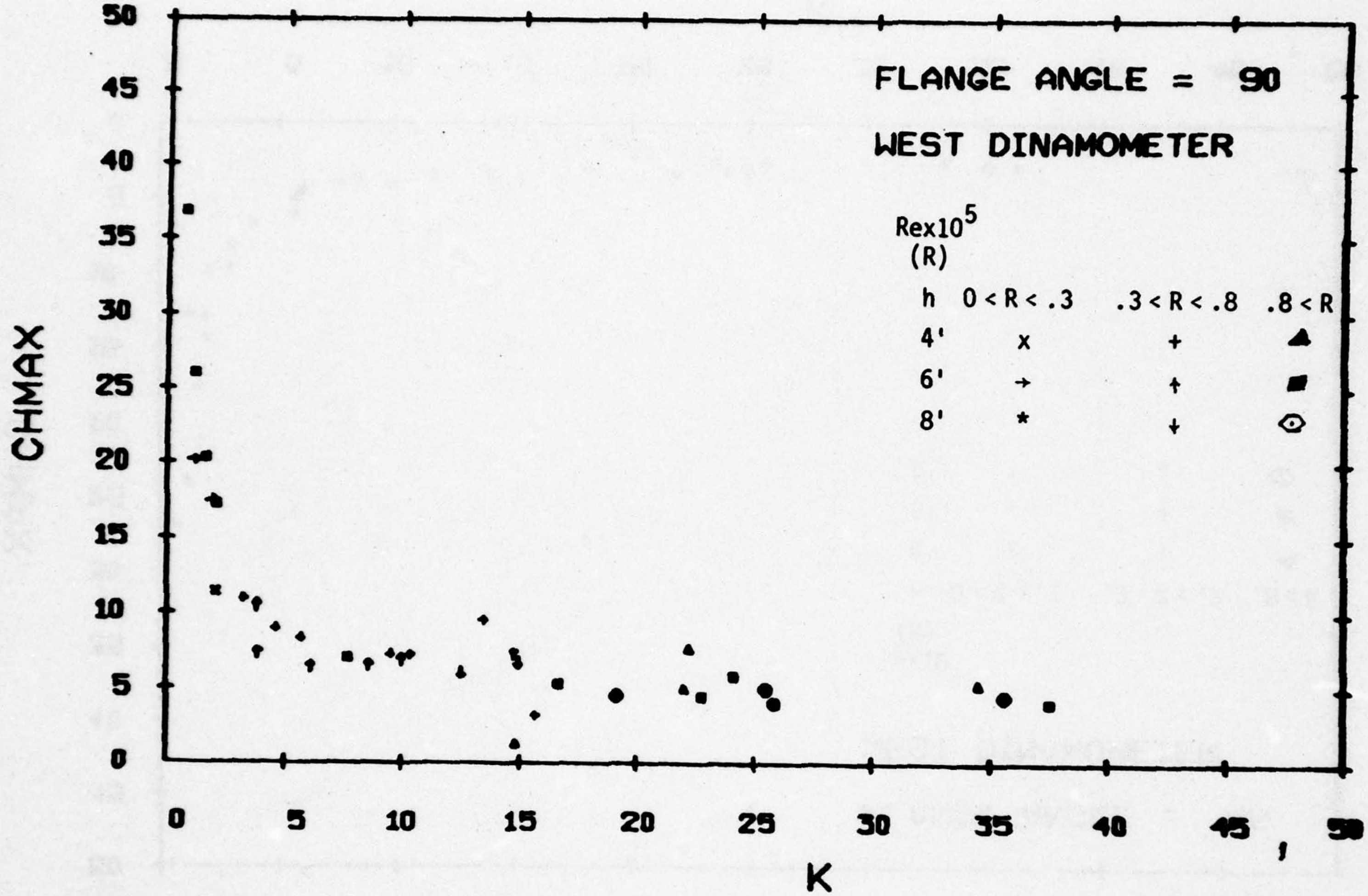

FIG. 45 - CHMAX vs. K for $\phi = 90^{o}$

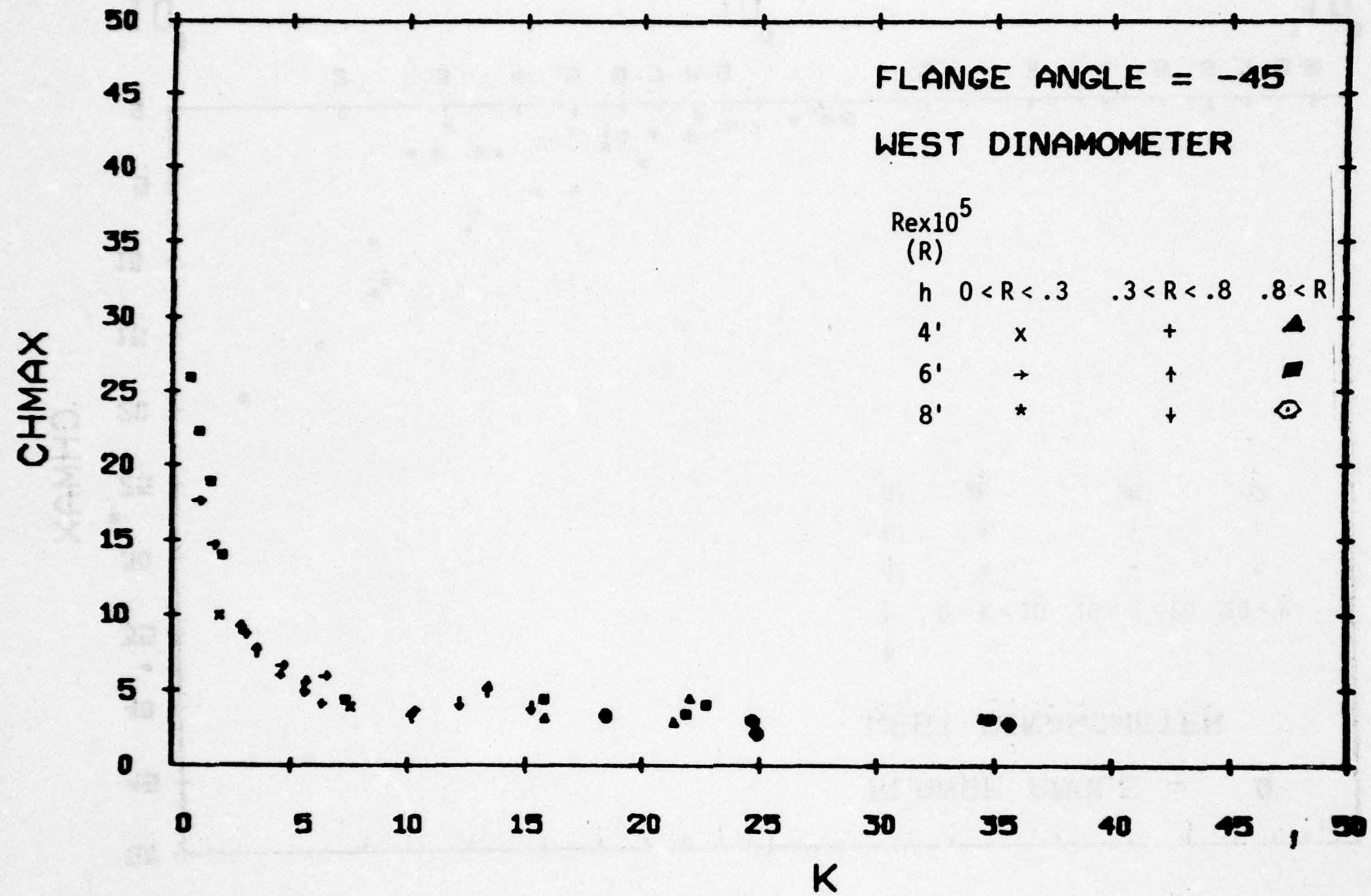

FIG. 46 - CHMAX vs. K for $\phi = -45^0$

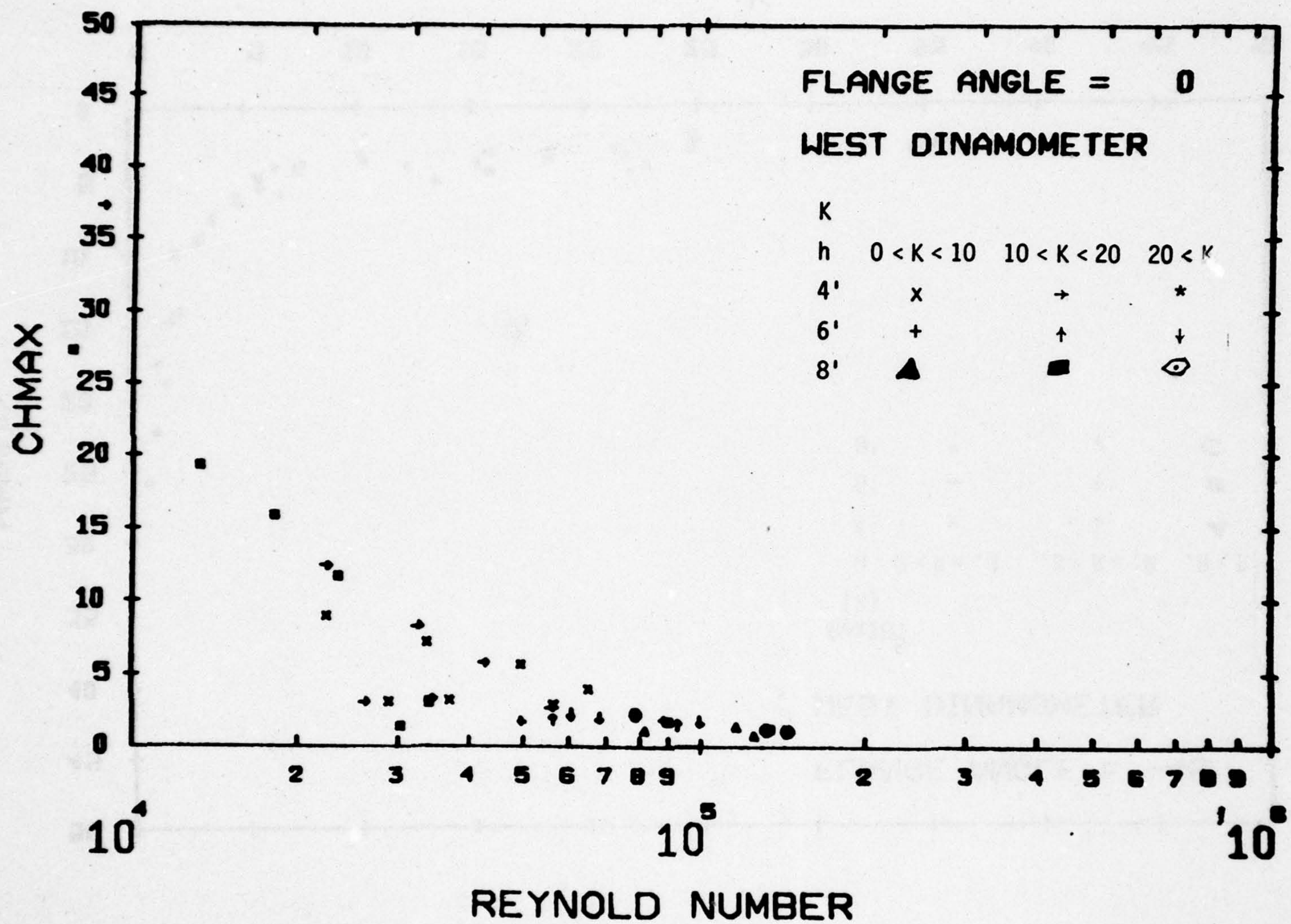

FIG. 47 - CHMAX vs. Re for $\phi = 0^0$

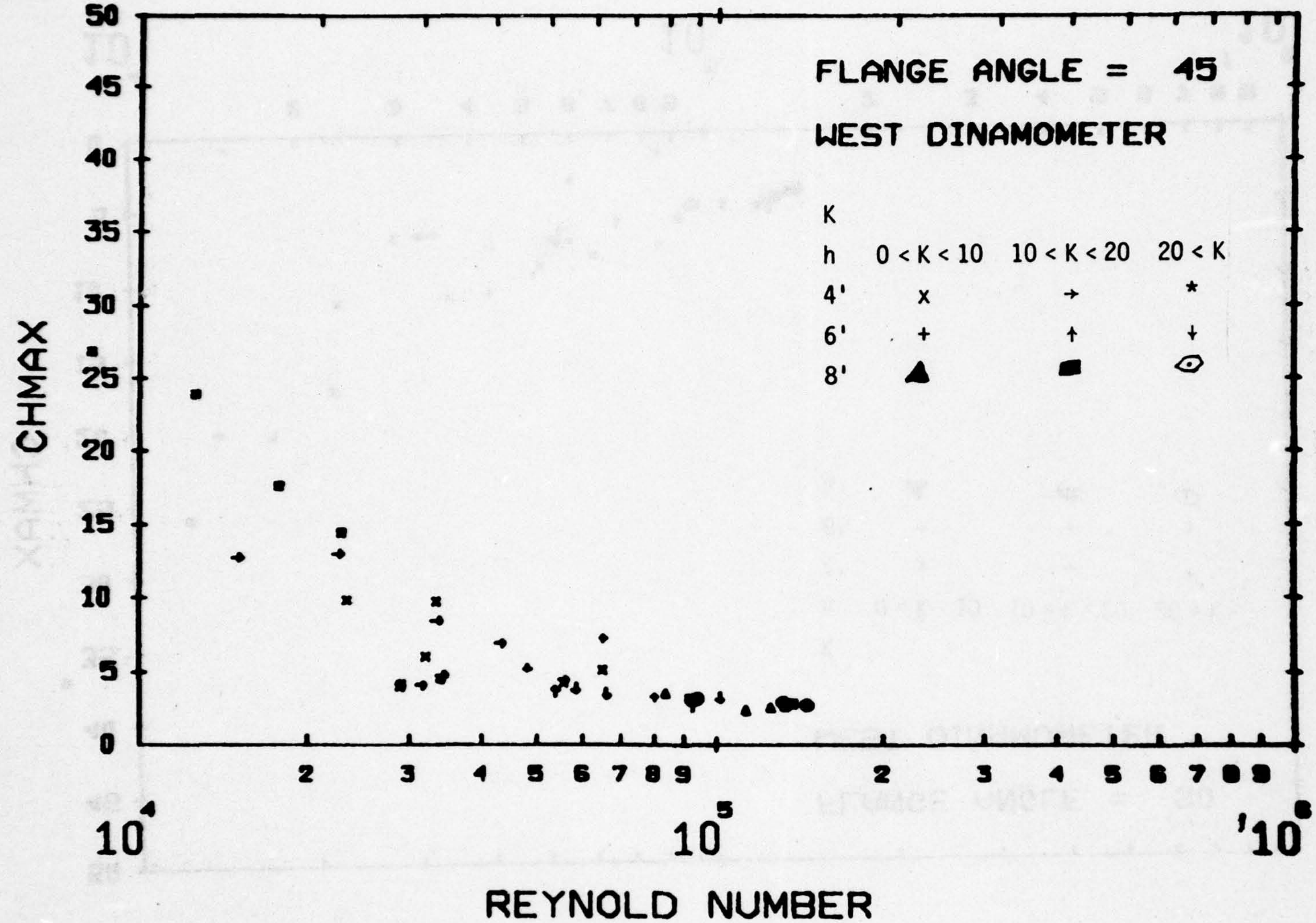

FIG. 48 - CHMAX vs. Re for $\phi = 45^0$

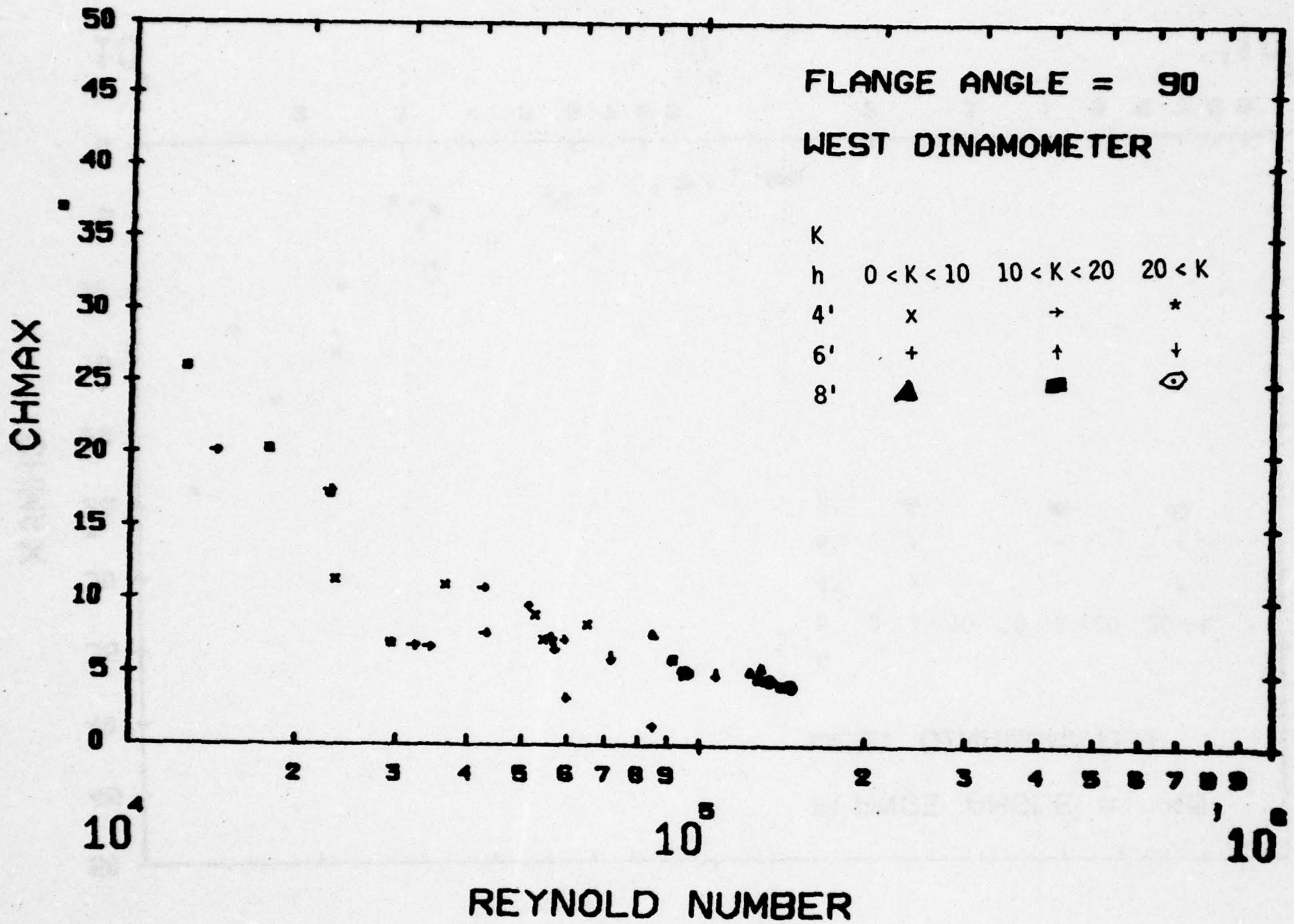

FIG. 49 - CHMAX vs. Re for $\phi = 90^0$

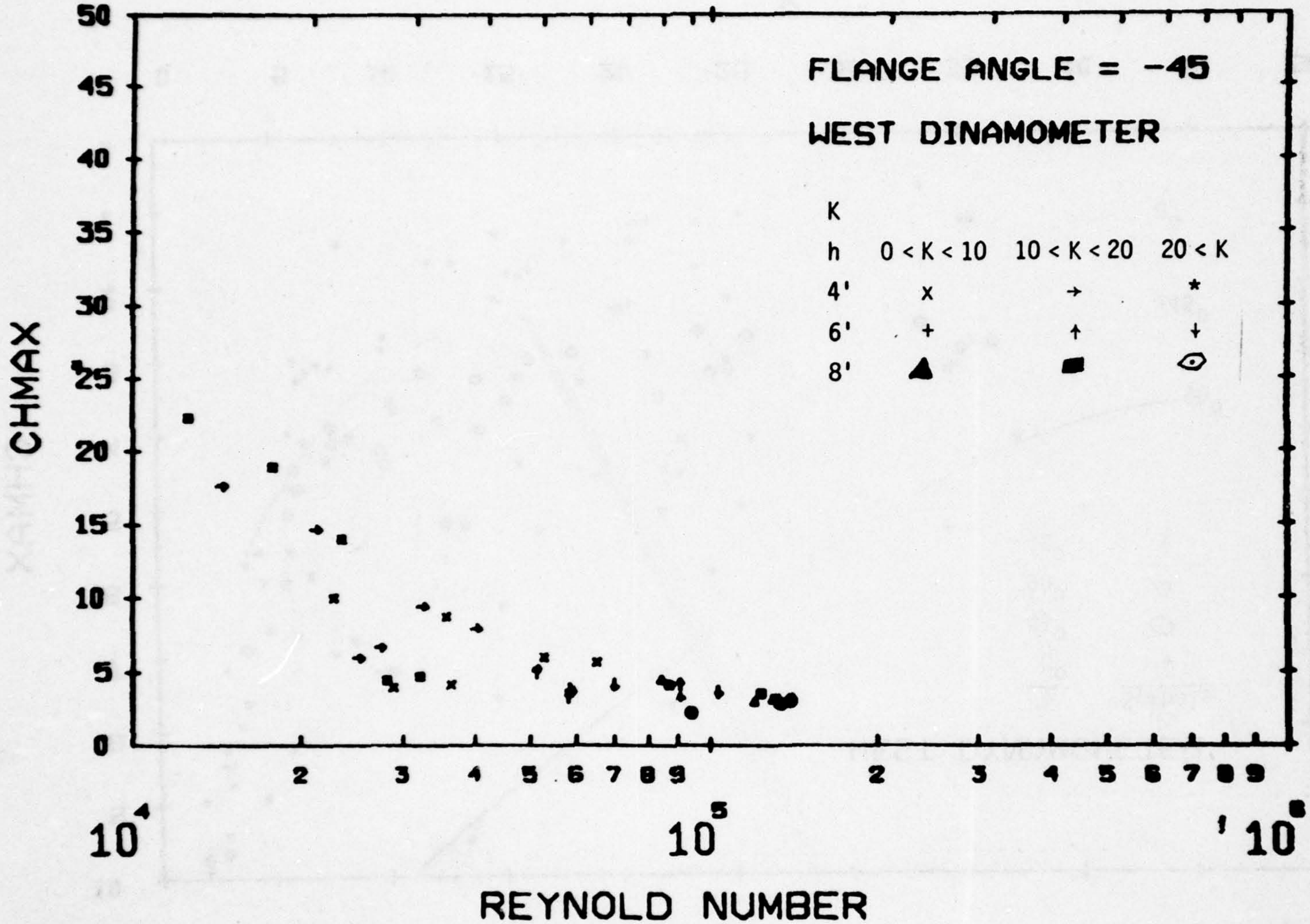

FIG. 50 - CHMAX vs. Re for $\phi = -45^0$

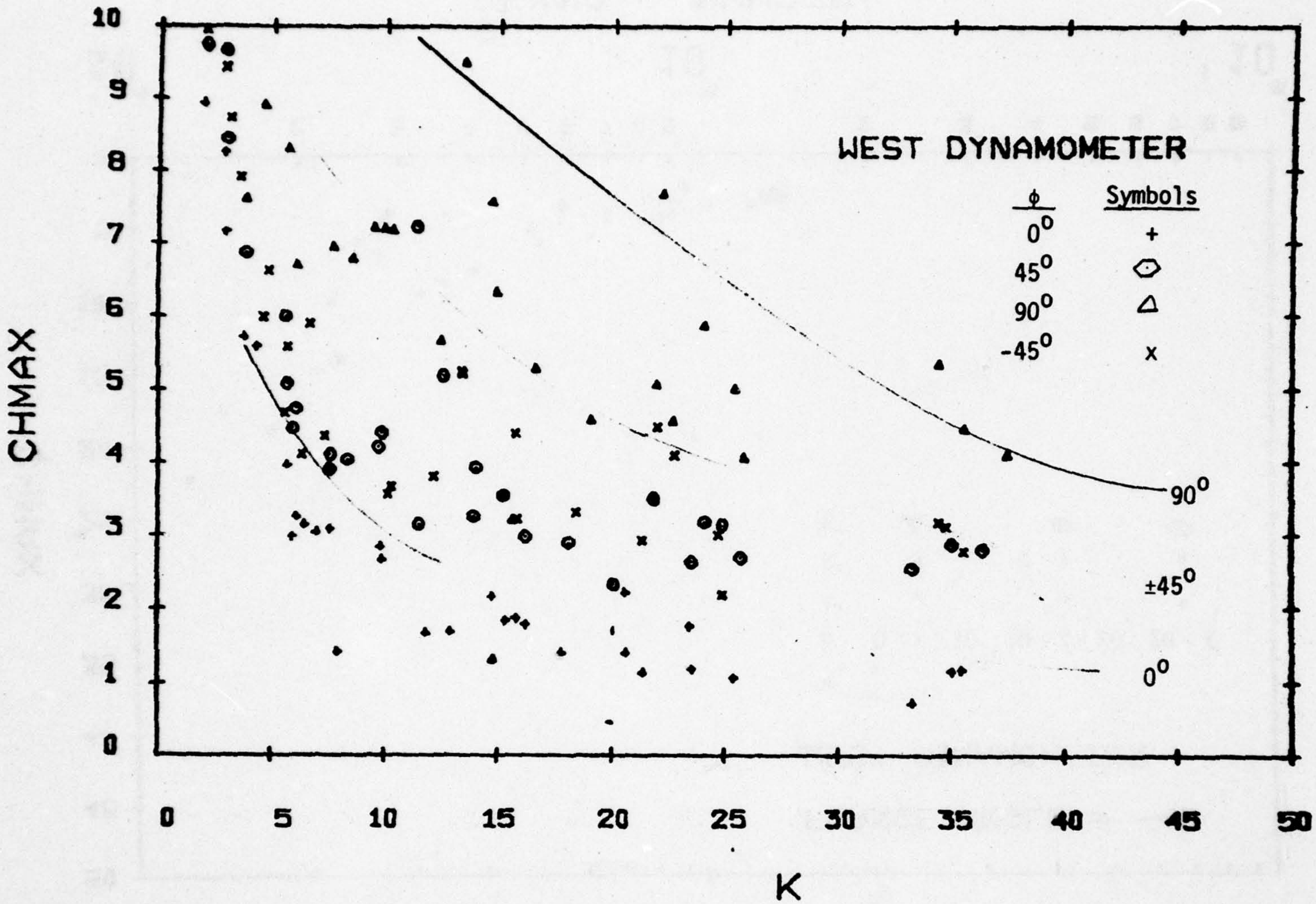

FIG. 51 - CHMAX vs. Re for all ϕs

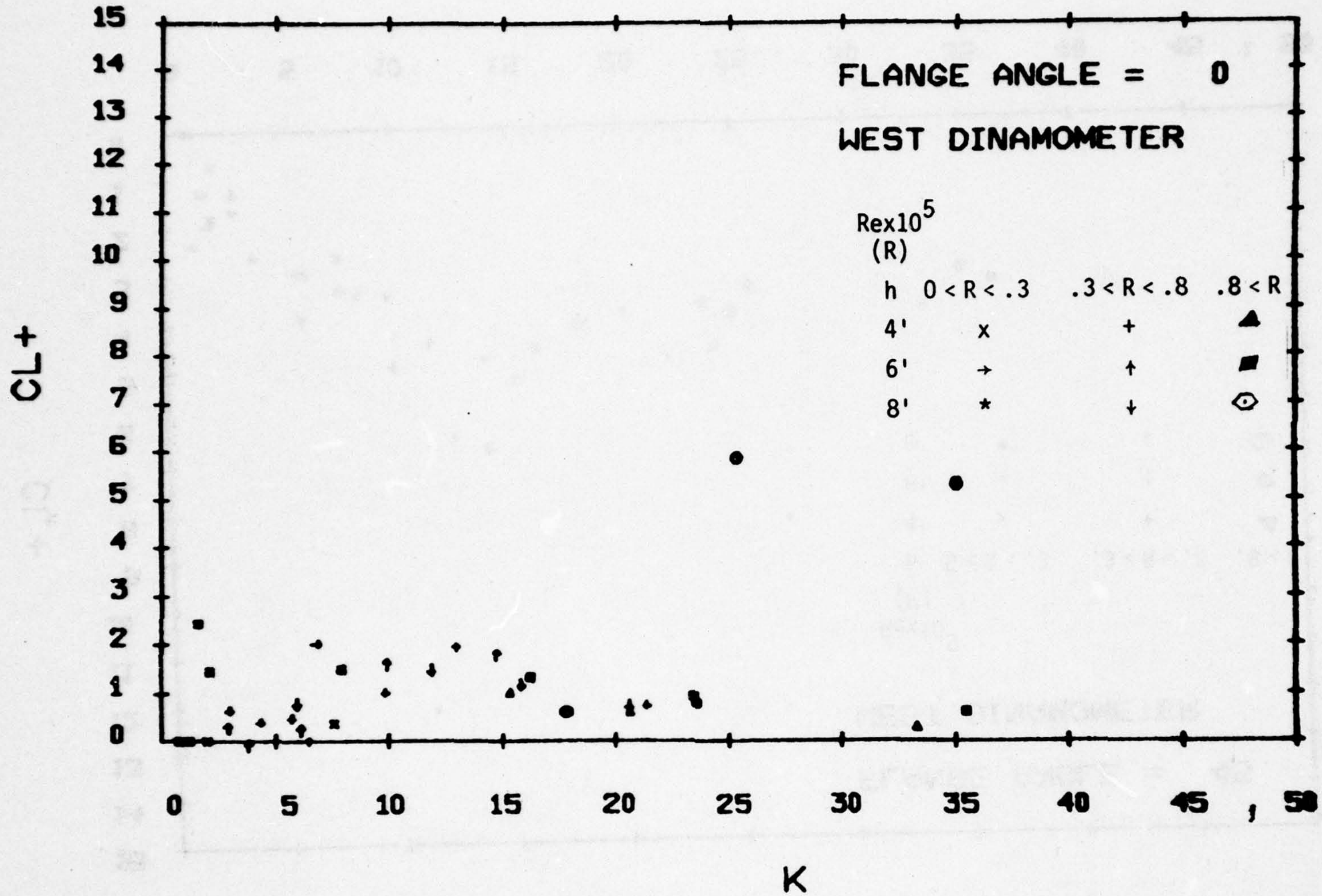

FIG. 52 - CL+ vs. K for $\phi = 0^0$

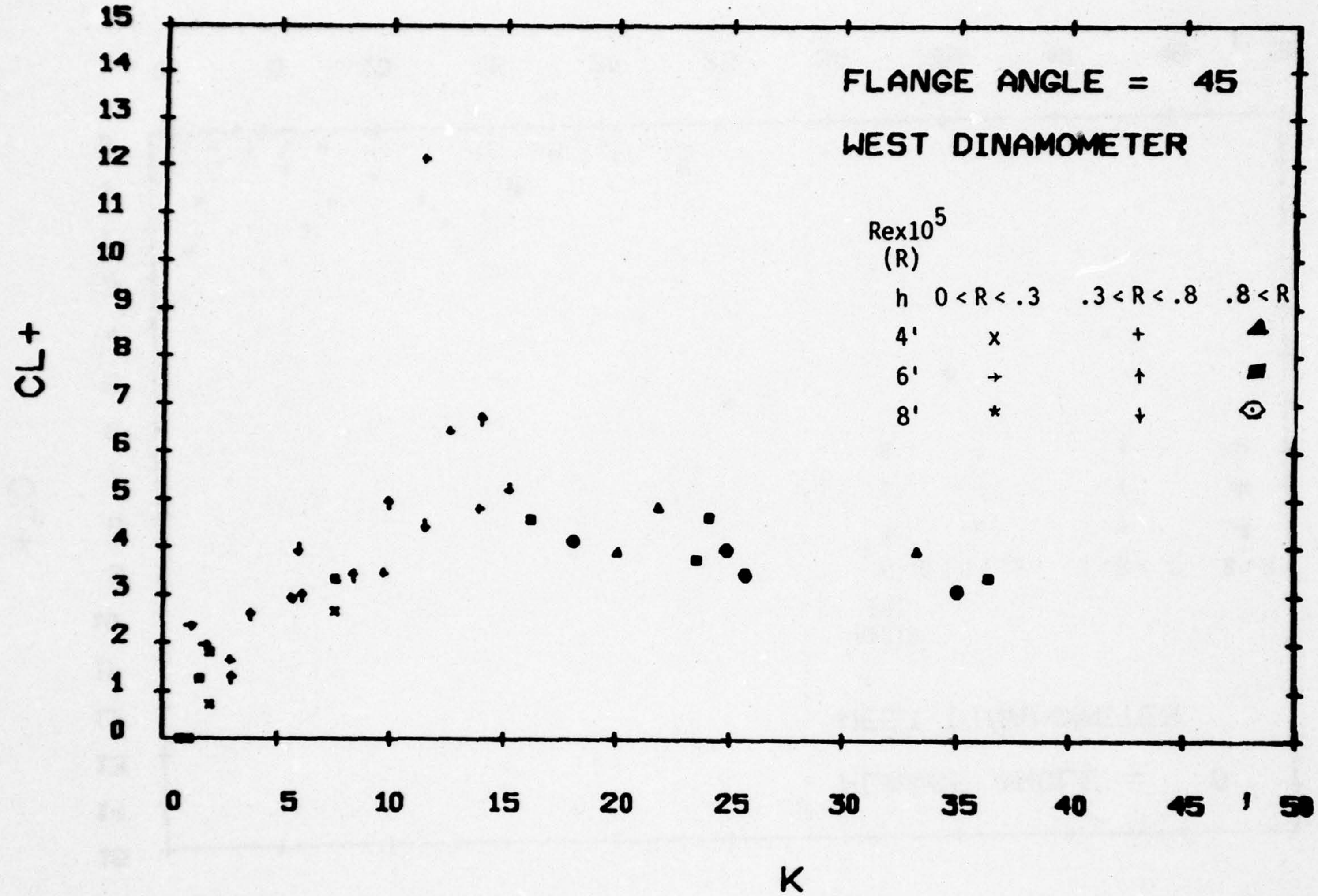

FIG. 53 - CL+ vs. K for $\phi = 45^0$

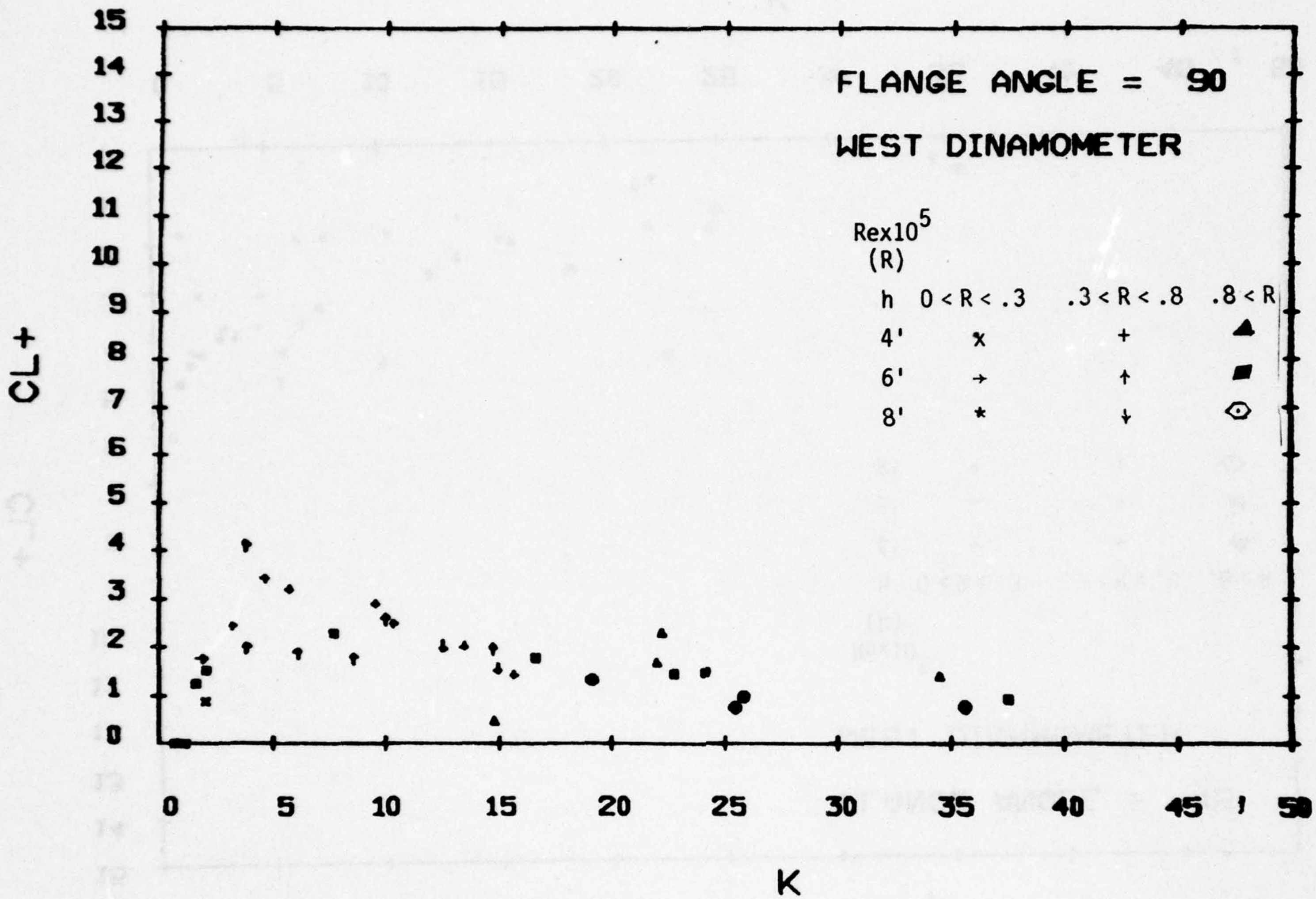

FIG. 54 - CL+ vs. K for $\phi = 90^0$

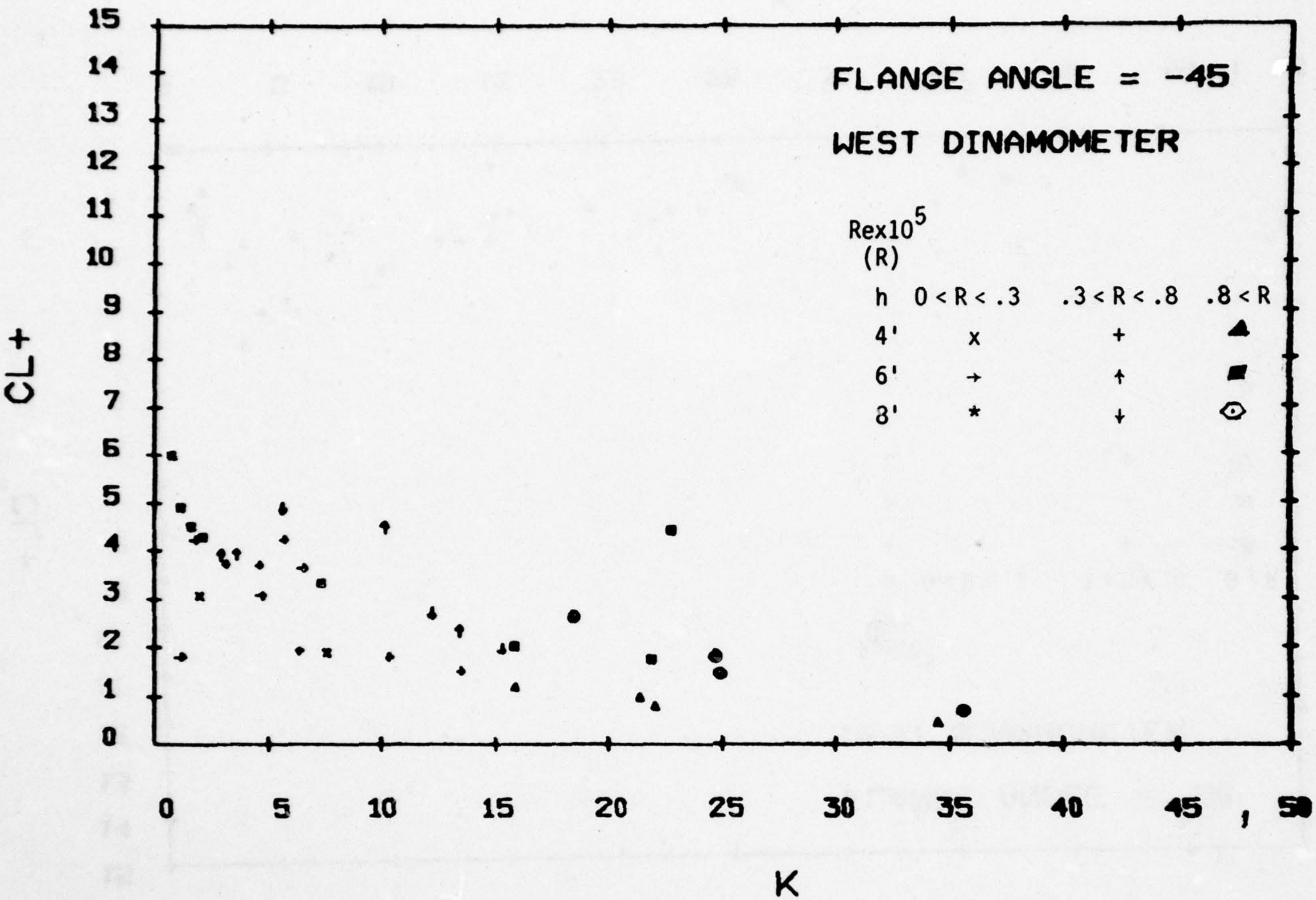

FIG. 55 - CL+ vs. K for $\phi = -45^0$

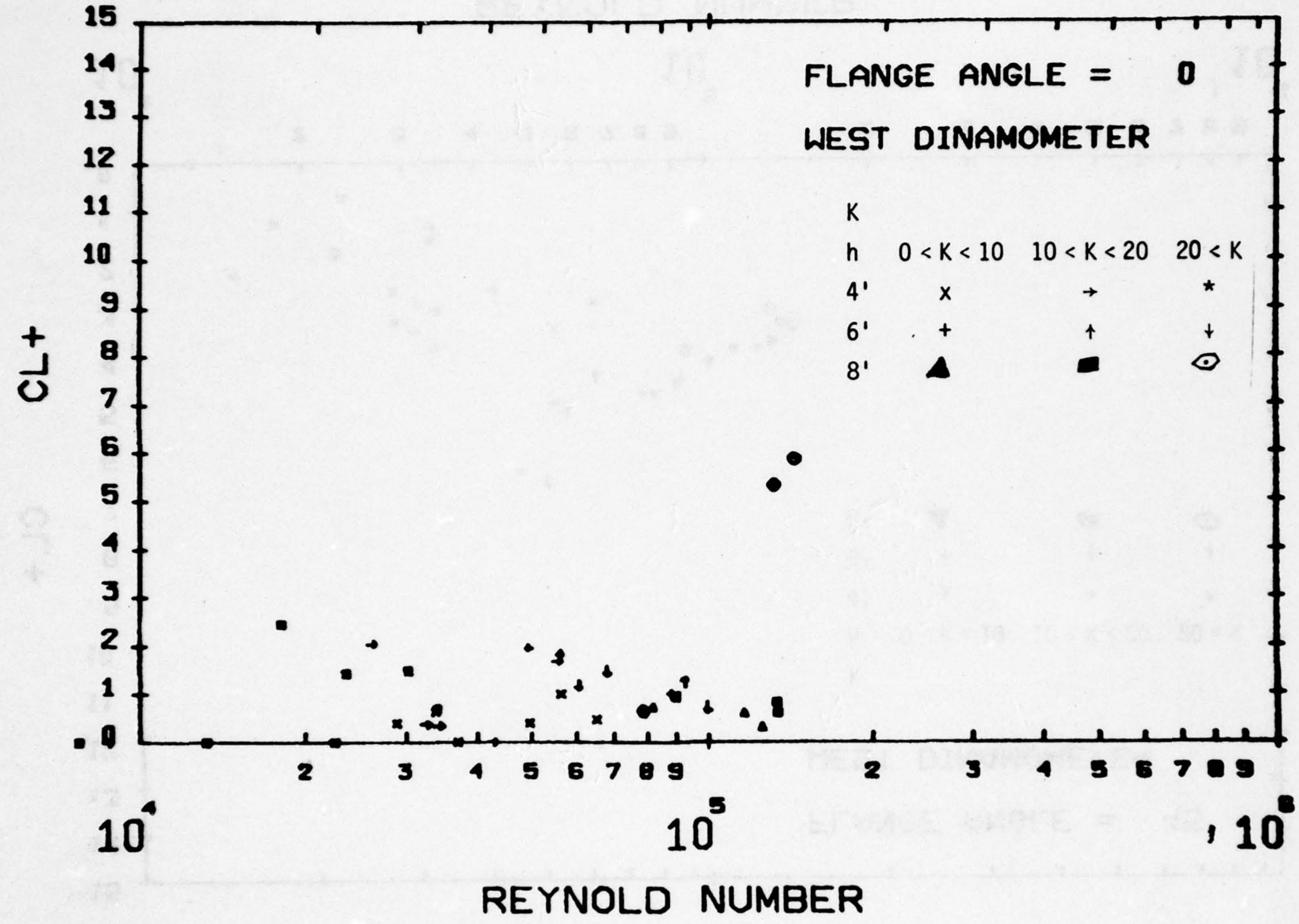

FIG. 56 - CL+ vs. Re for $\phi = 0^0$

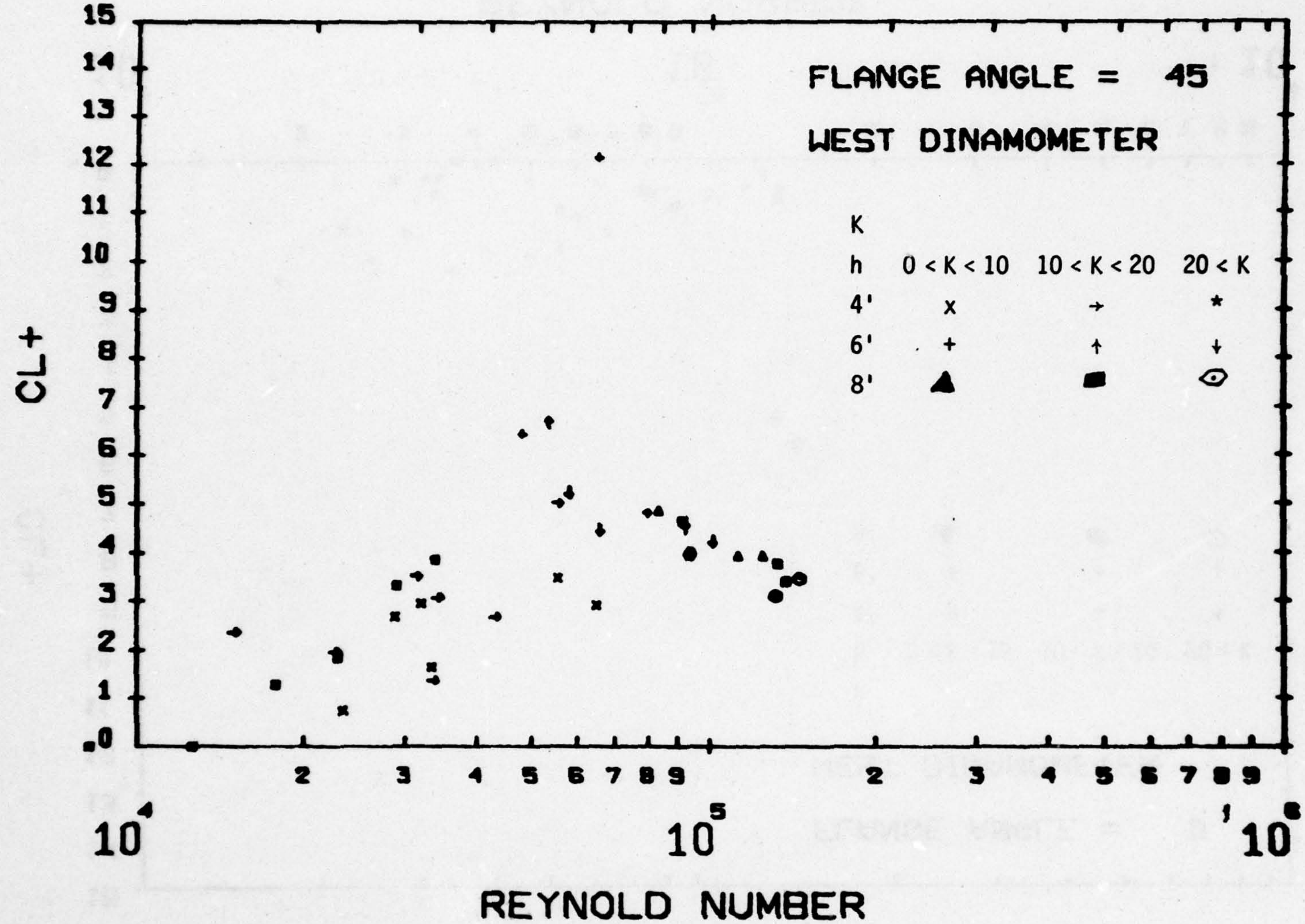

FIG. 57 - CL+ vs. Re for $\phi = 45^0$

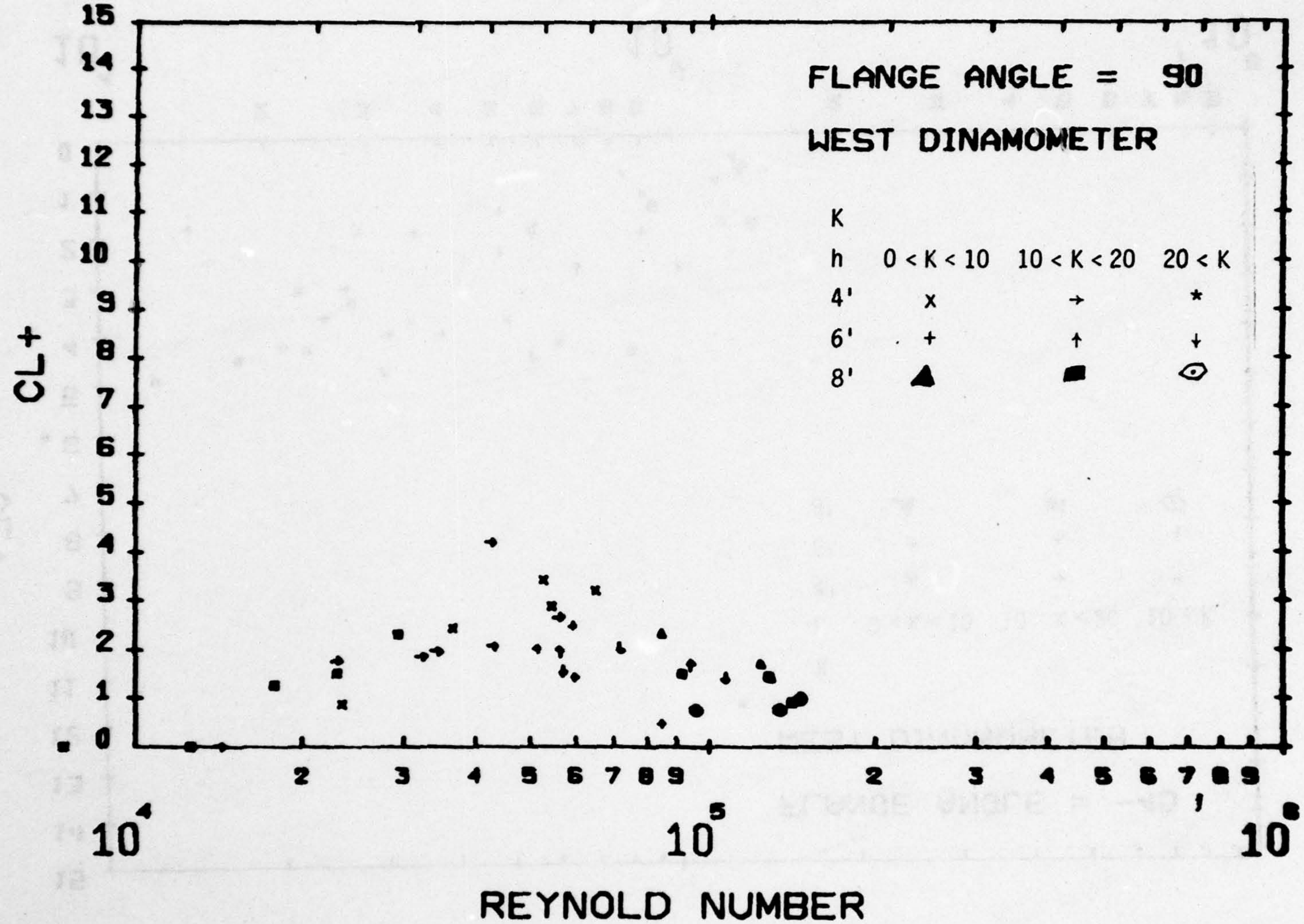

FIG. 58 - CL+ vs. Re for $\phi = 90^0$

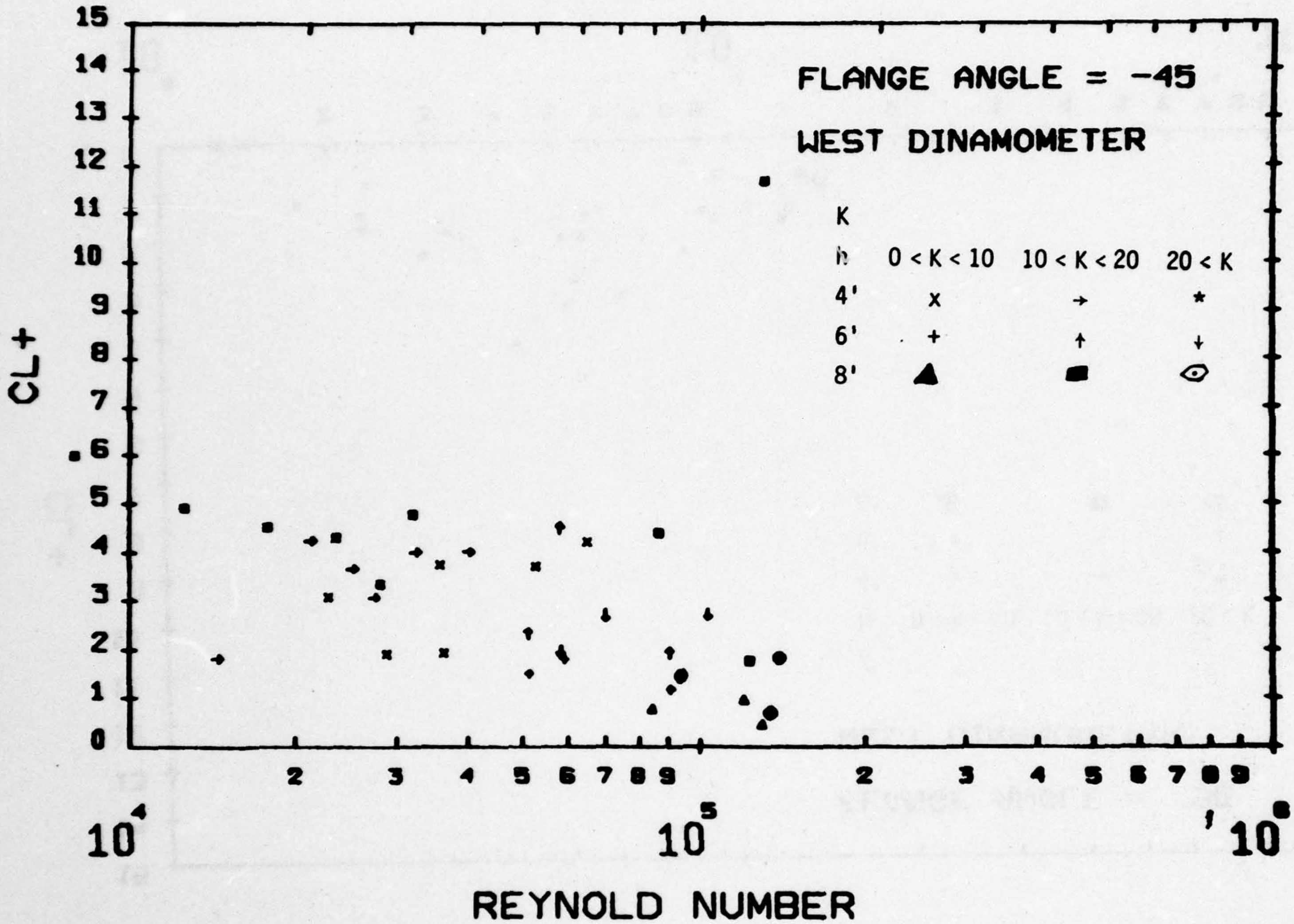

FIG. 59 - CL+ vs. Re for $\phi = -45^{0}$

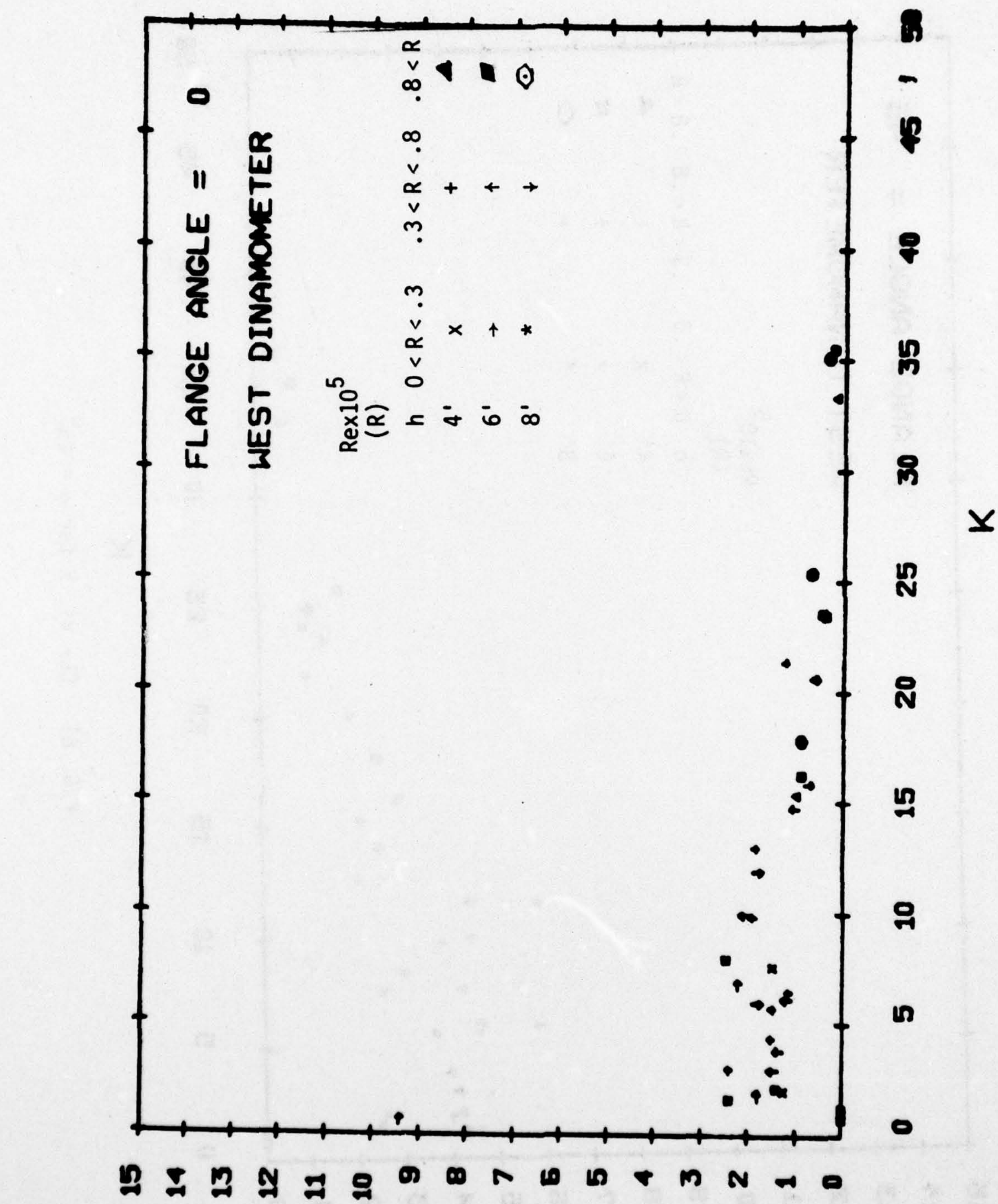

FIG. 60 - CL- vs. K for $\phi = 0^0$

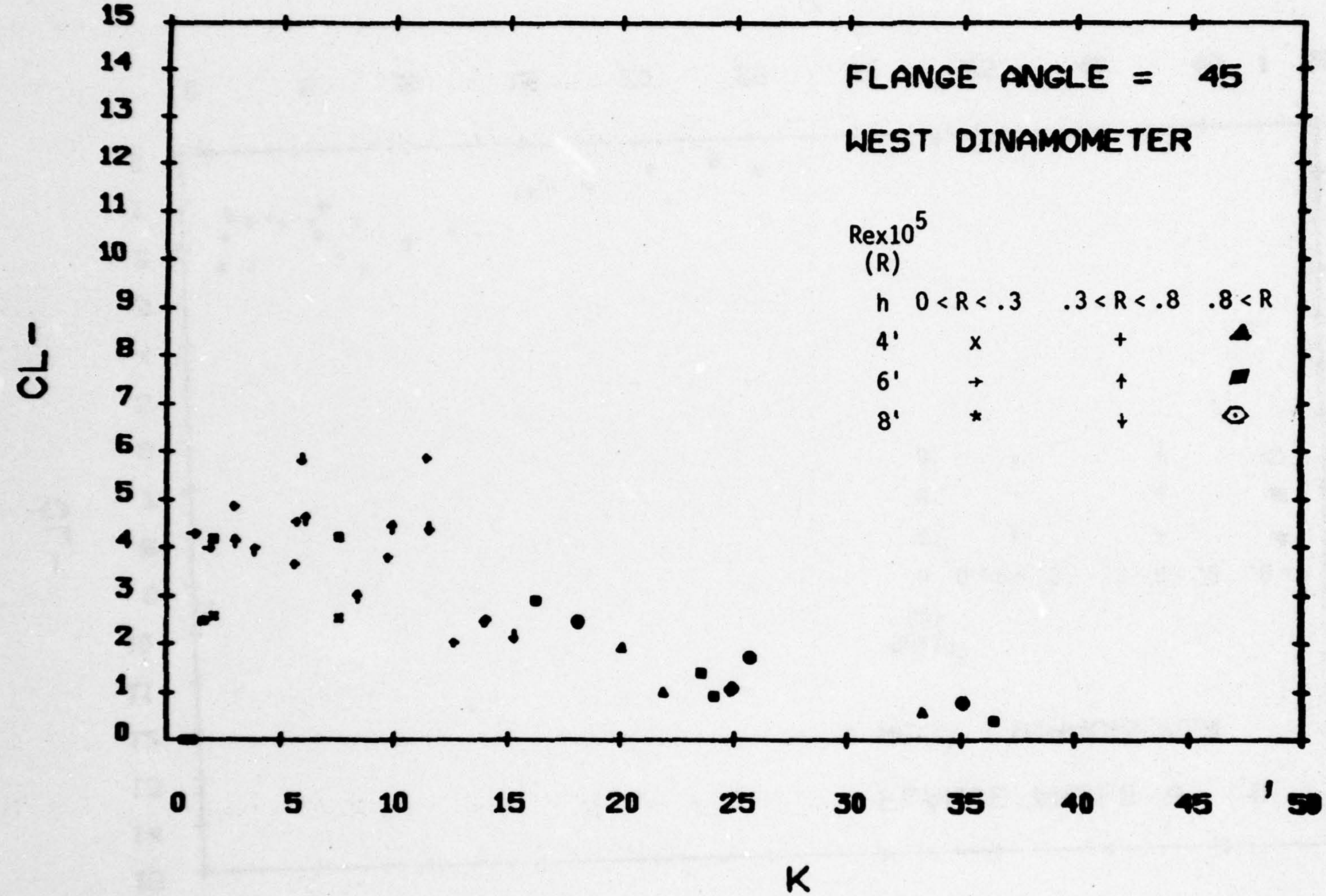

FIG. 61 - CL- vs. K for $\phi = 45^{0}$

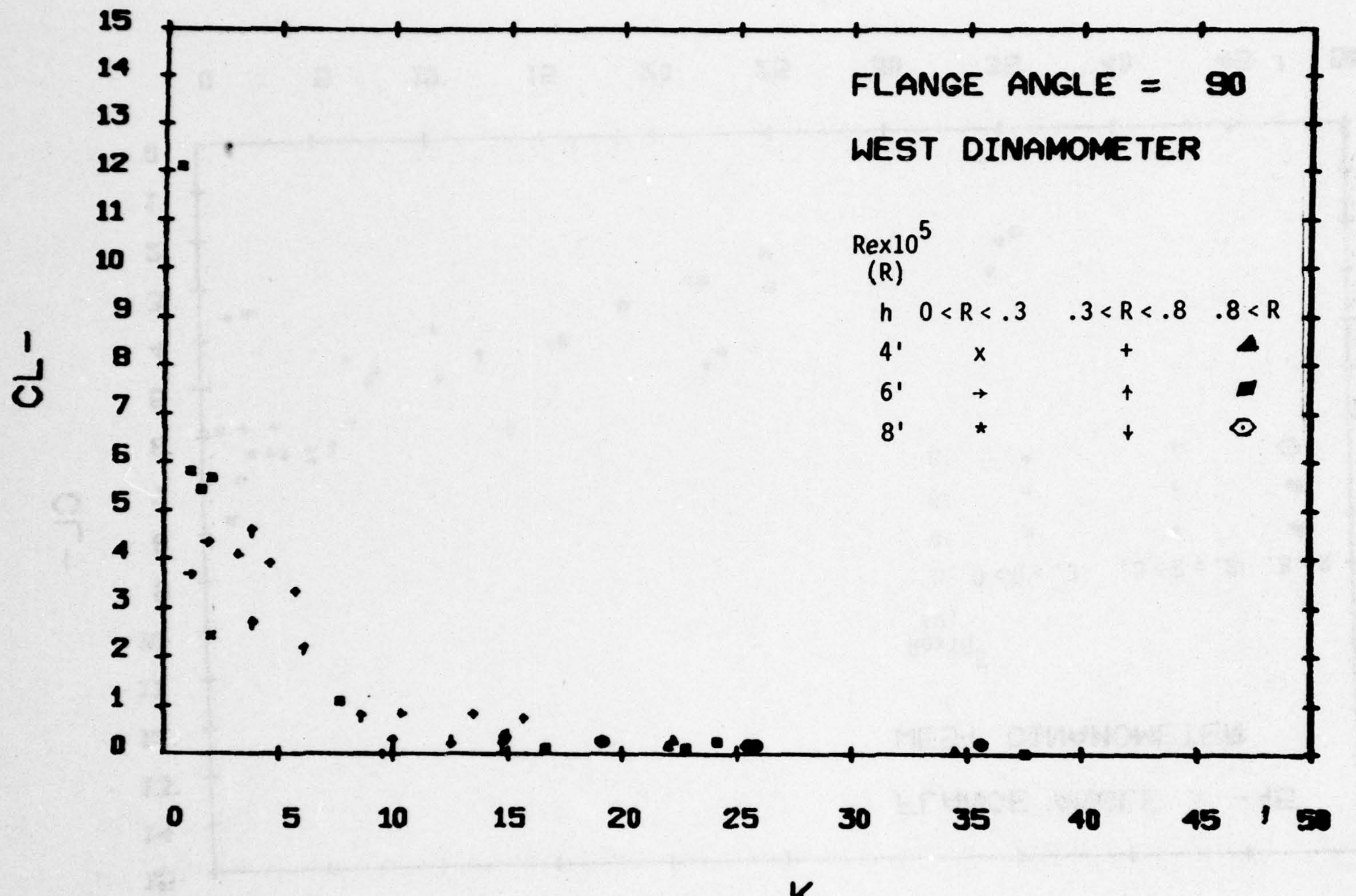

FIG. 62 - CL- vs. K for $\phi = 90^0$

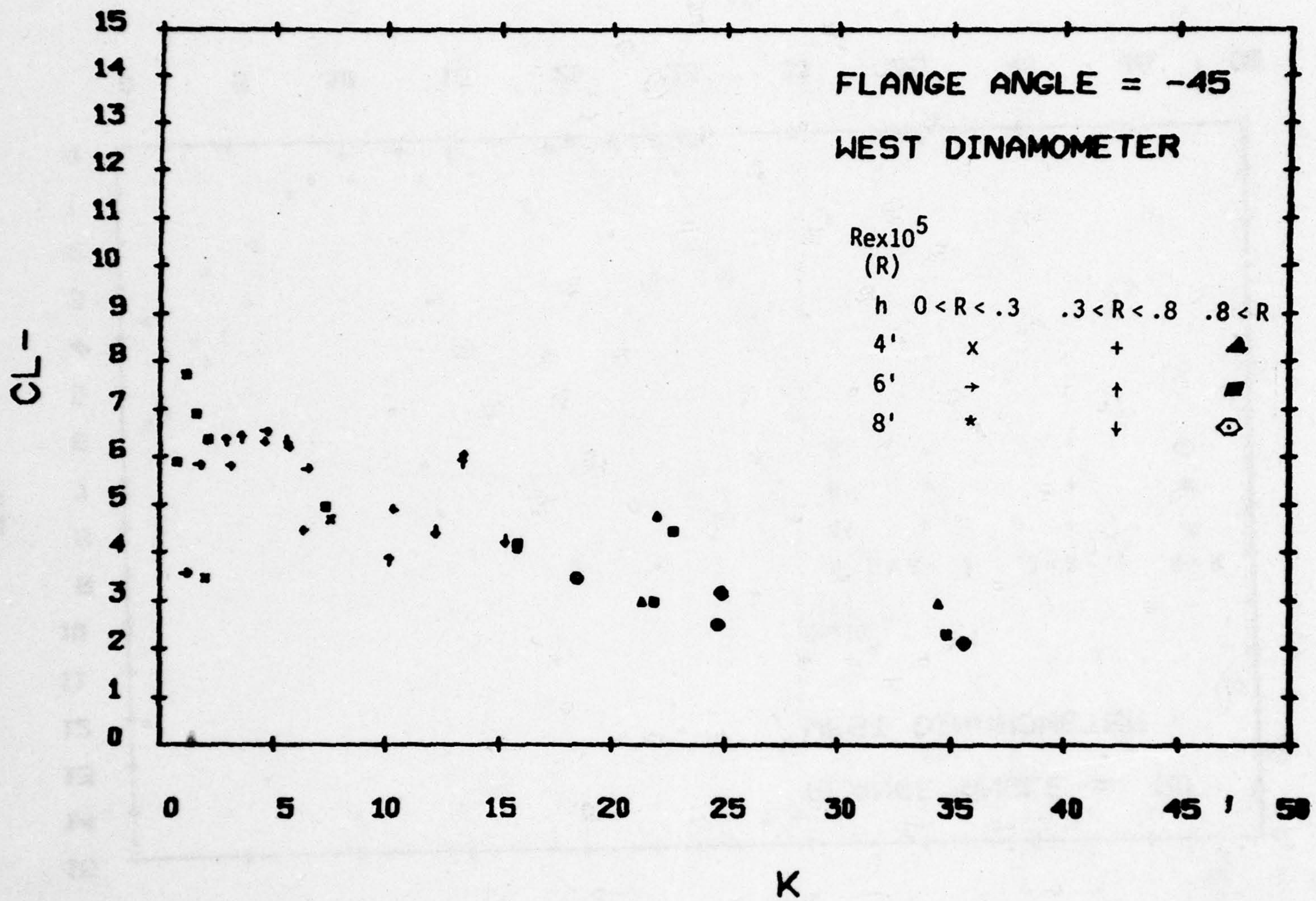

FIG. 63 - CL- vs. K for $\phi = -45^{o}$

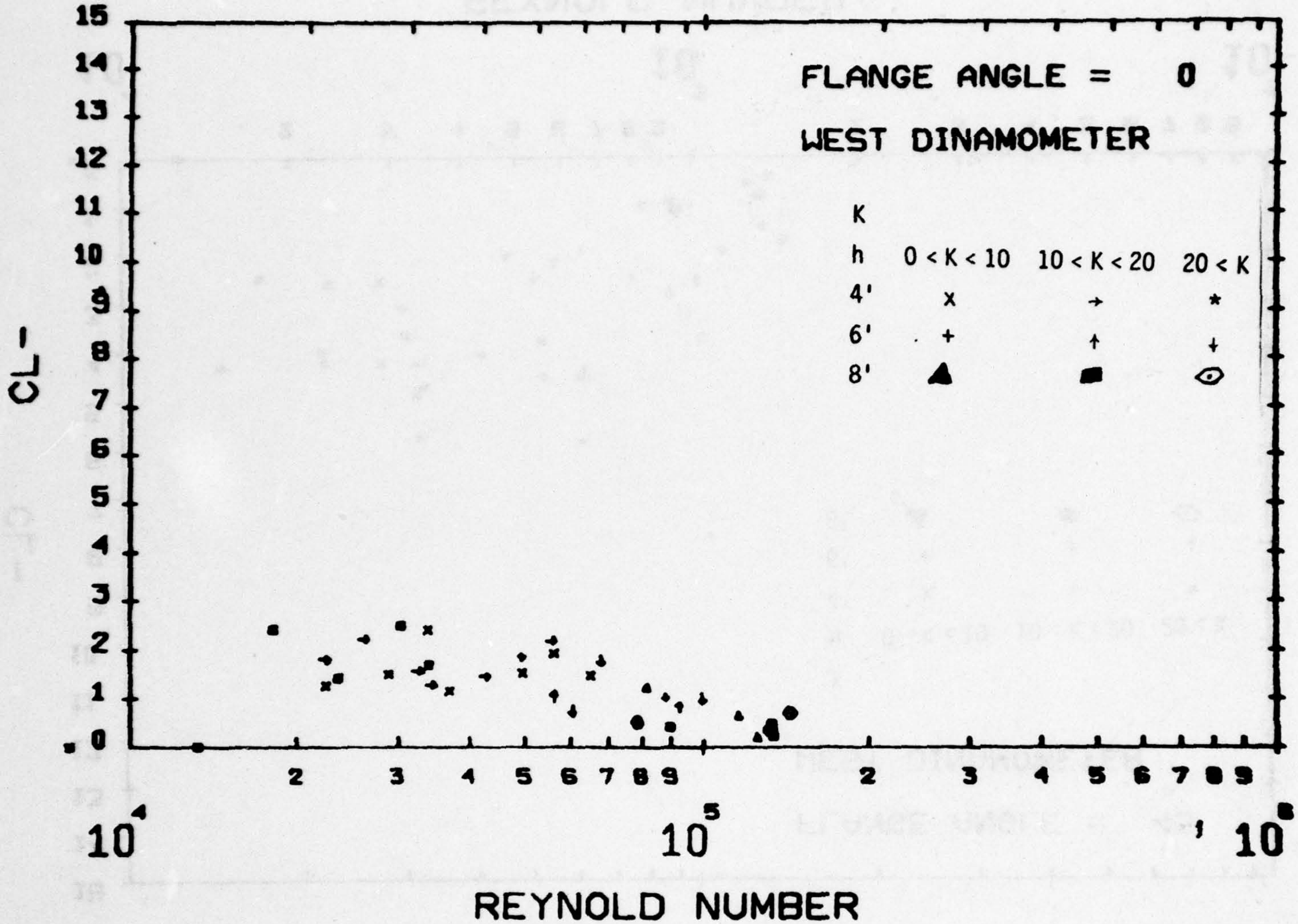

FIG. 64 - CL- vs. Re for $\phi = 0^0$

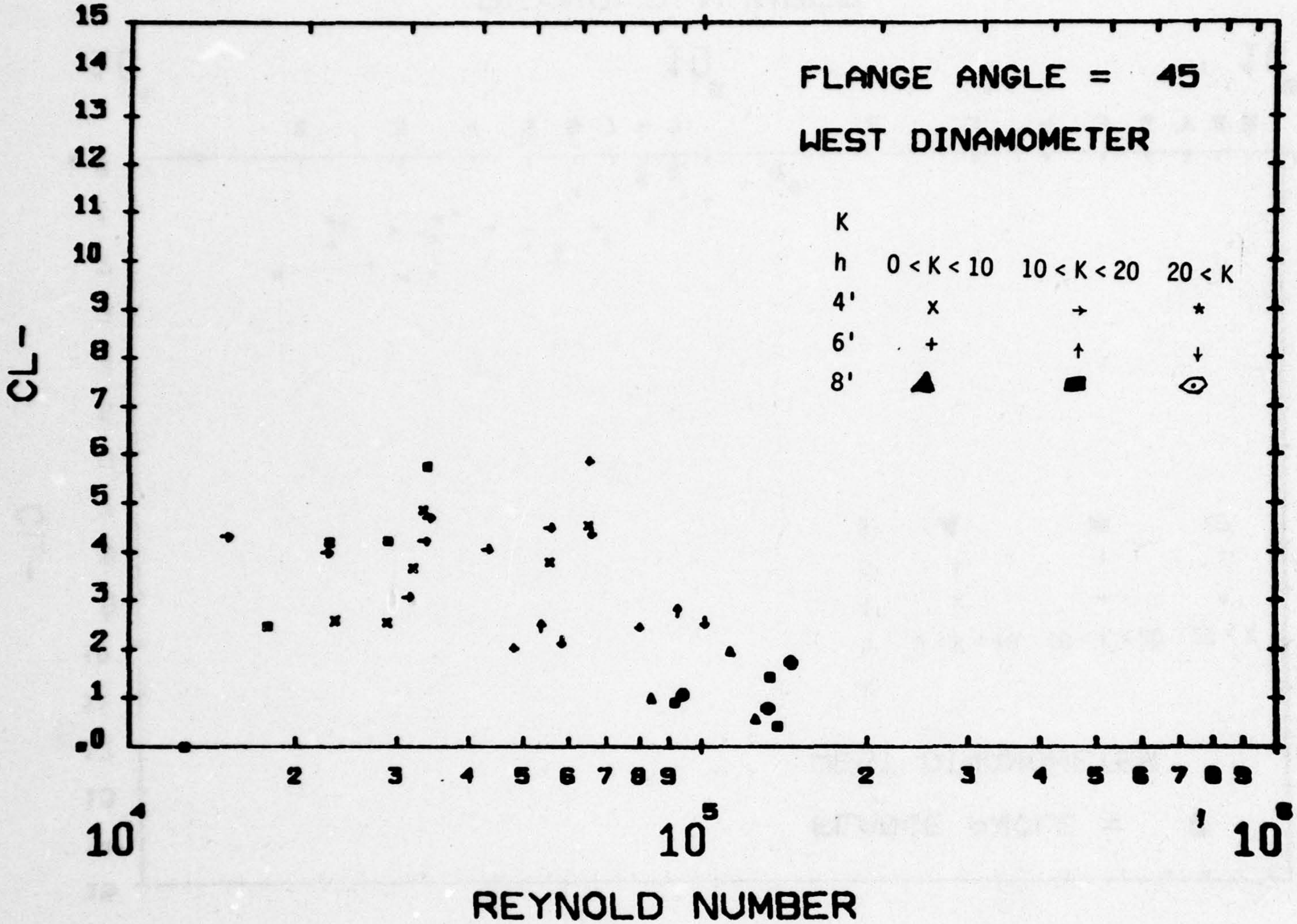

FIG. 65 - CL- vs. Re for $\phi = 45^0$

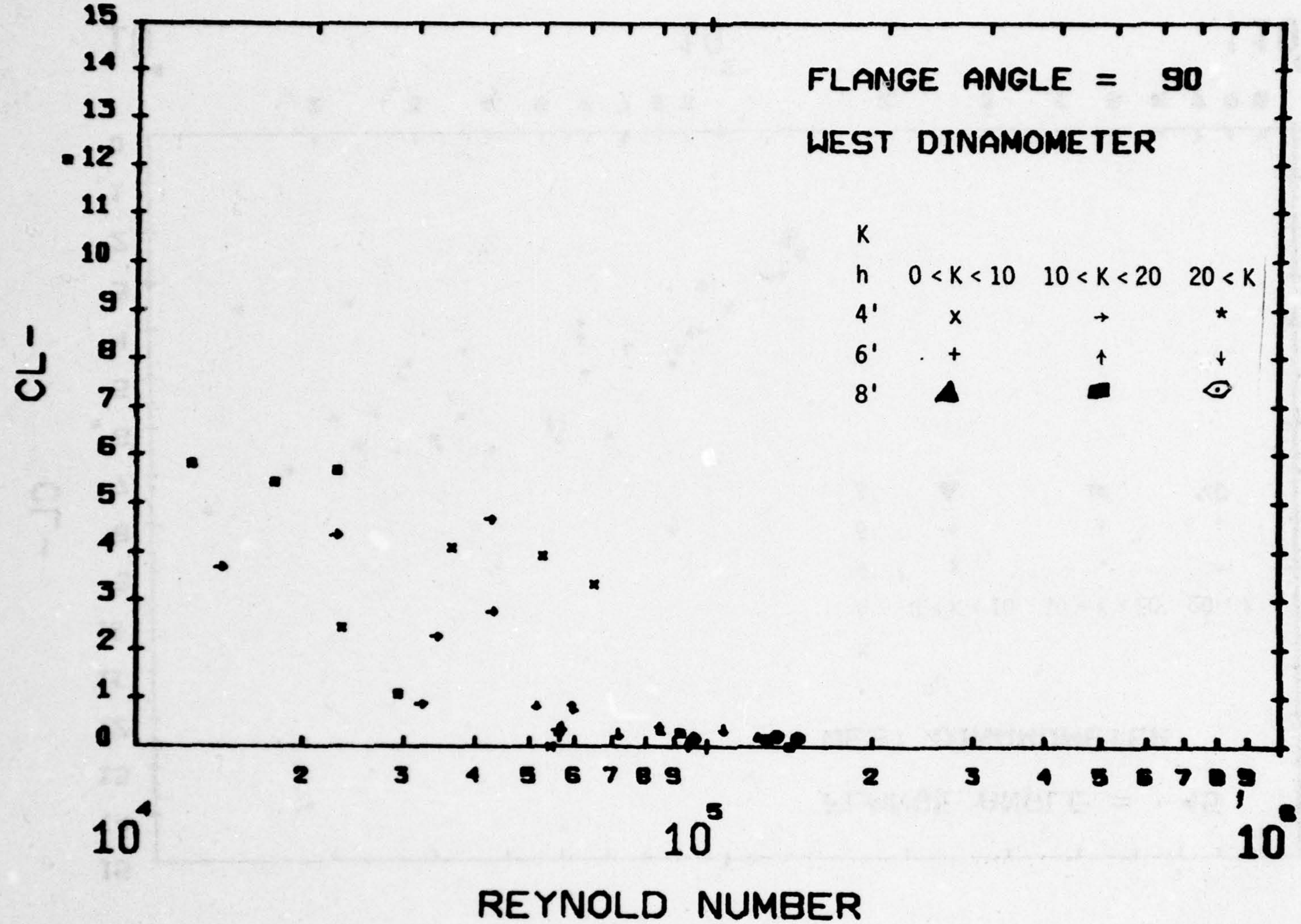

FIG. 66 - CL- vs. Re for $\phi = 90^0$

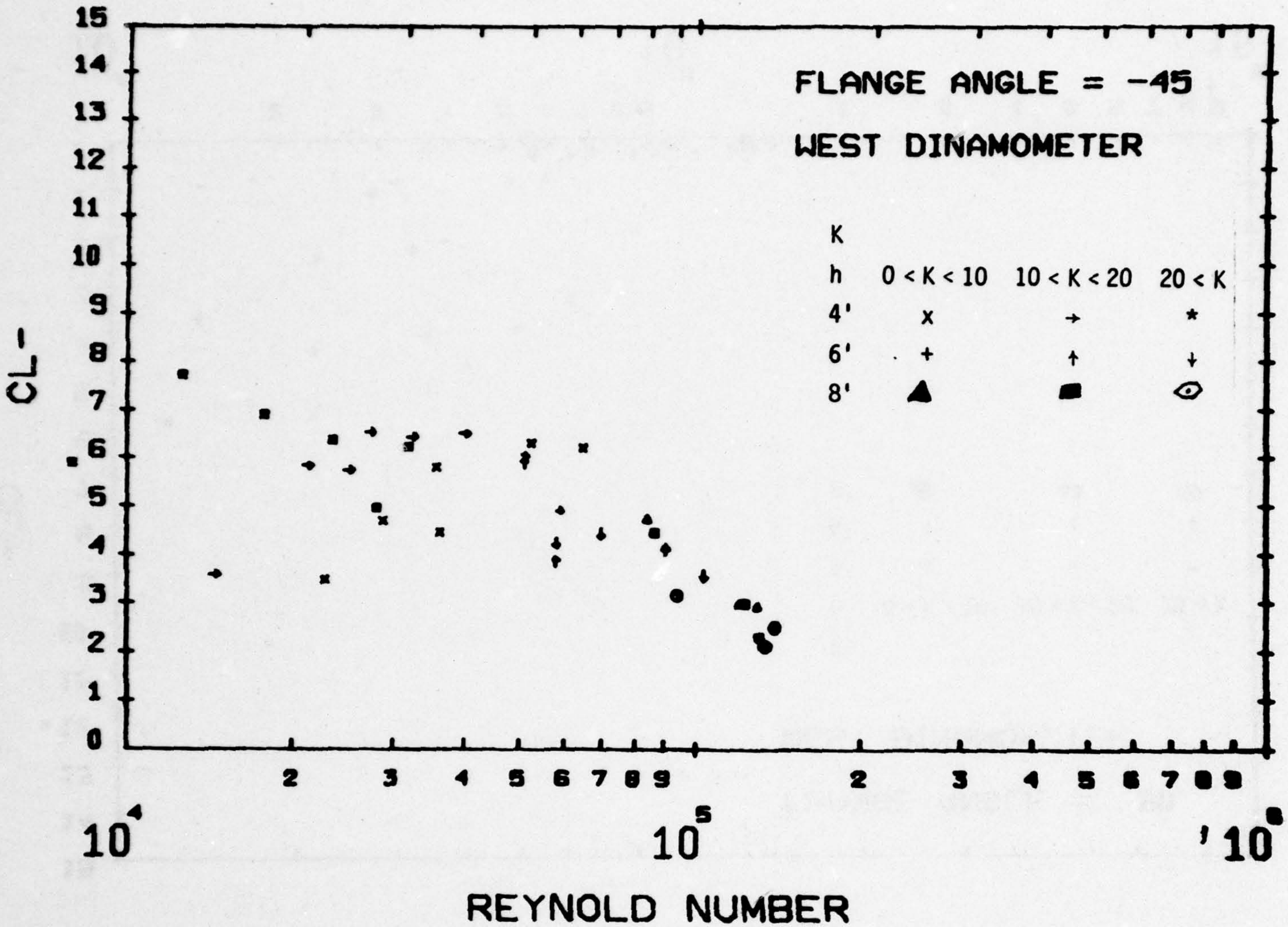

FIG. 67 - CL- vs. Re for $\phi = -45^0$

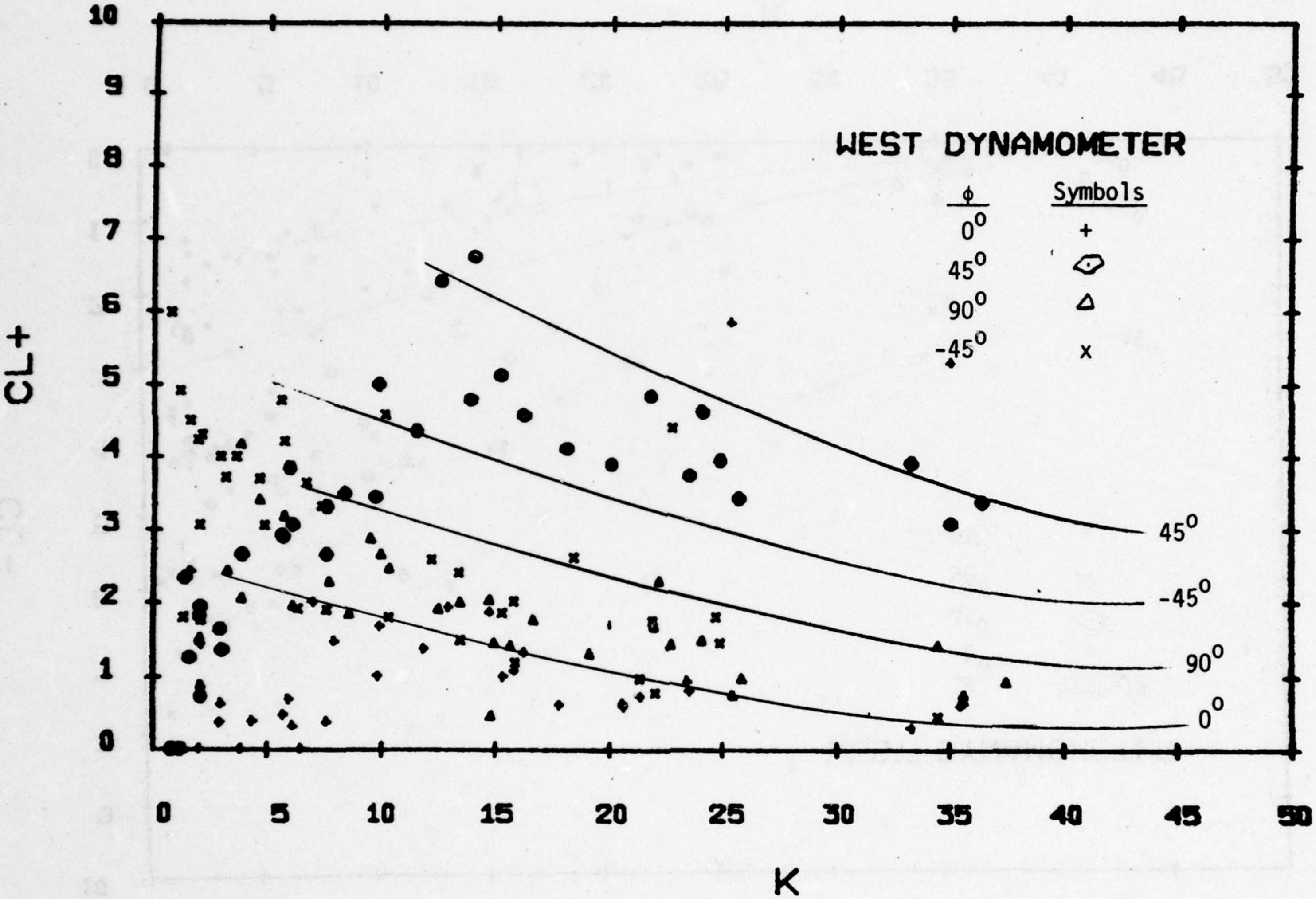

FIG. 68 - CL+ vs. K for all ϕs

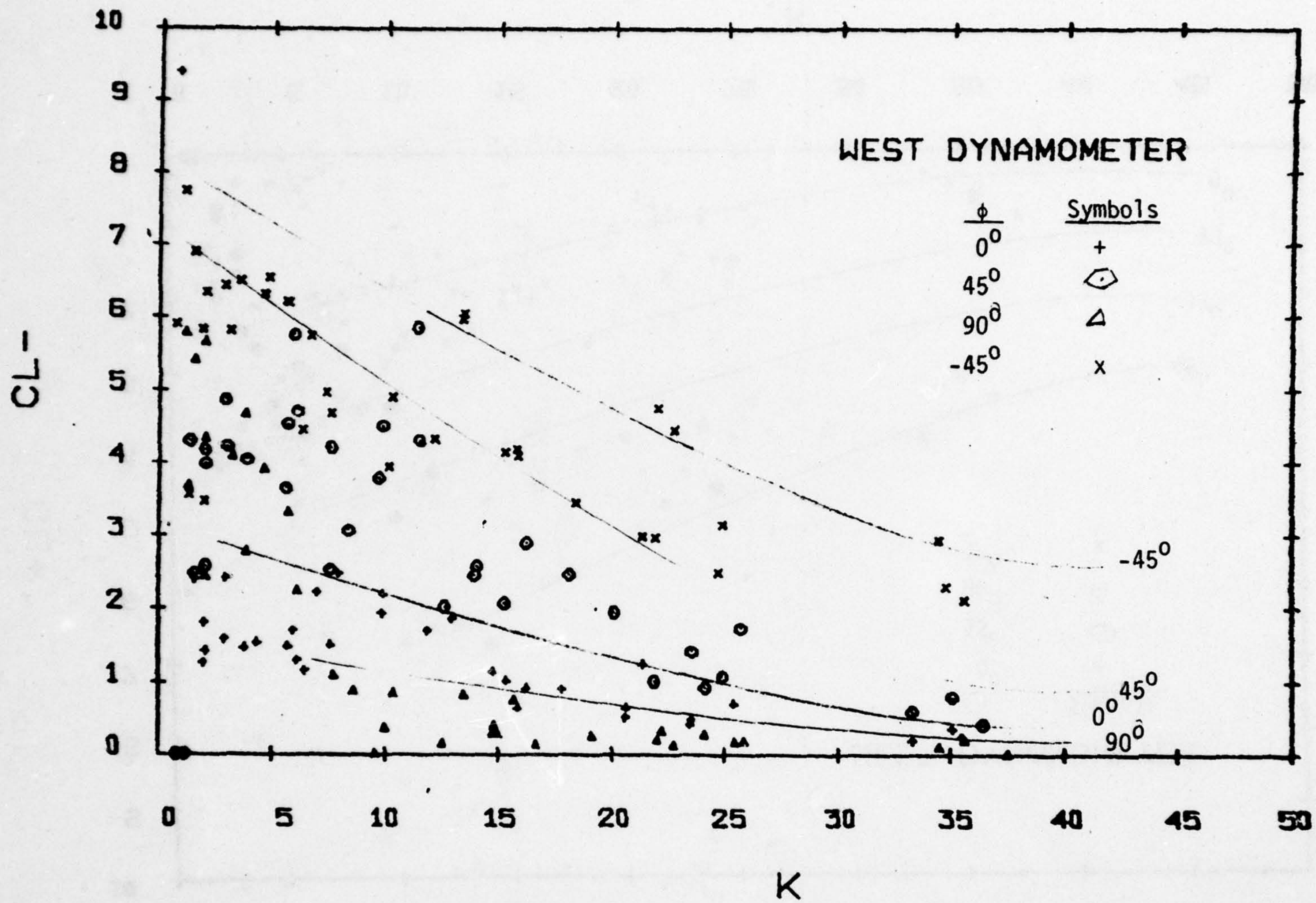

FIG. 69 - CL- vs. K for all ϕs

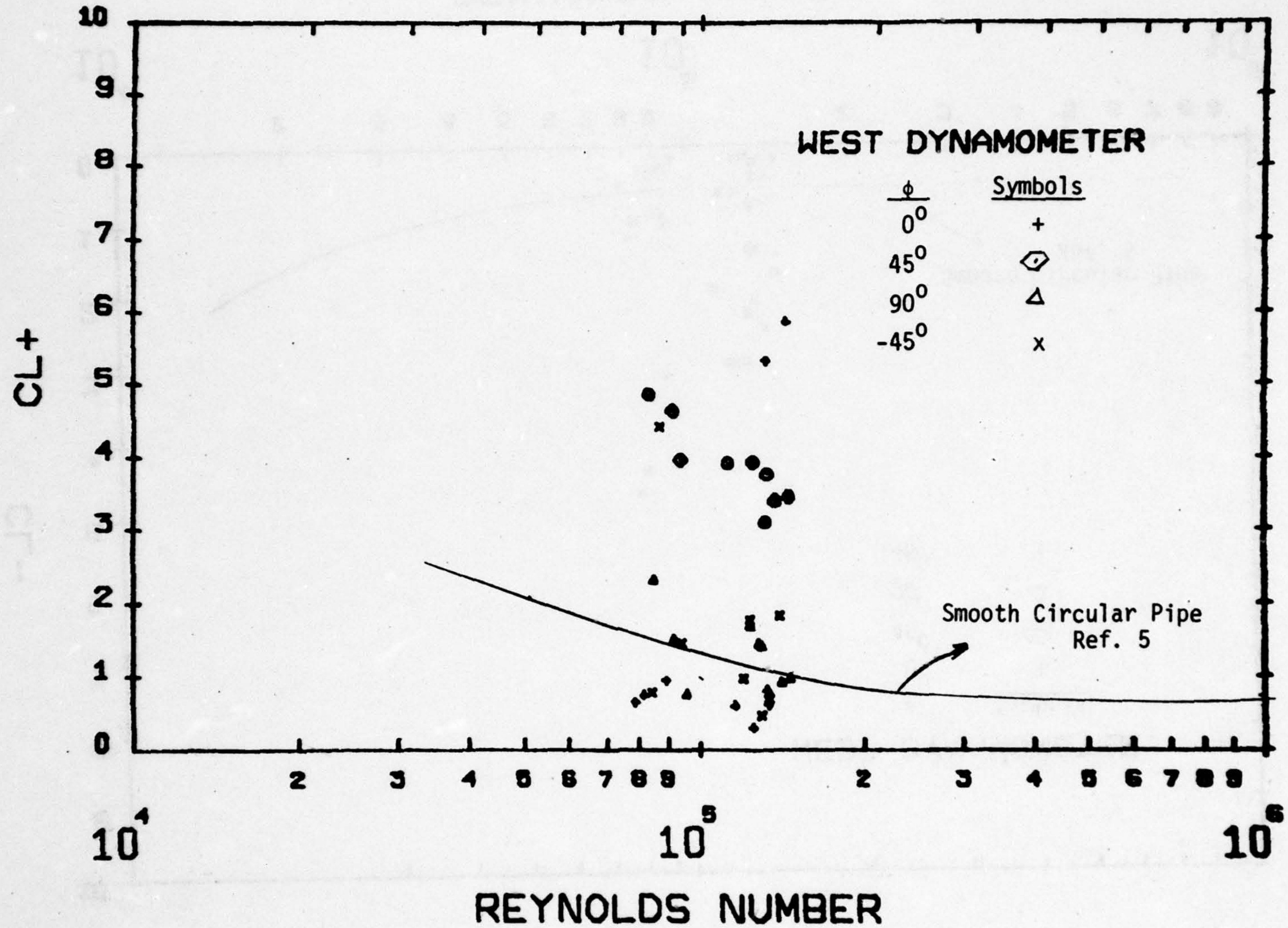

FIG. 70 - CL+ vs. Re for all ϕs, K >20

70

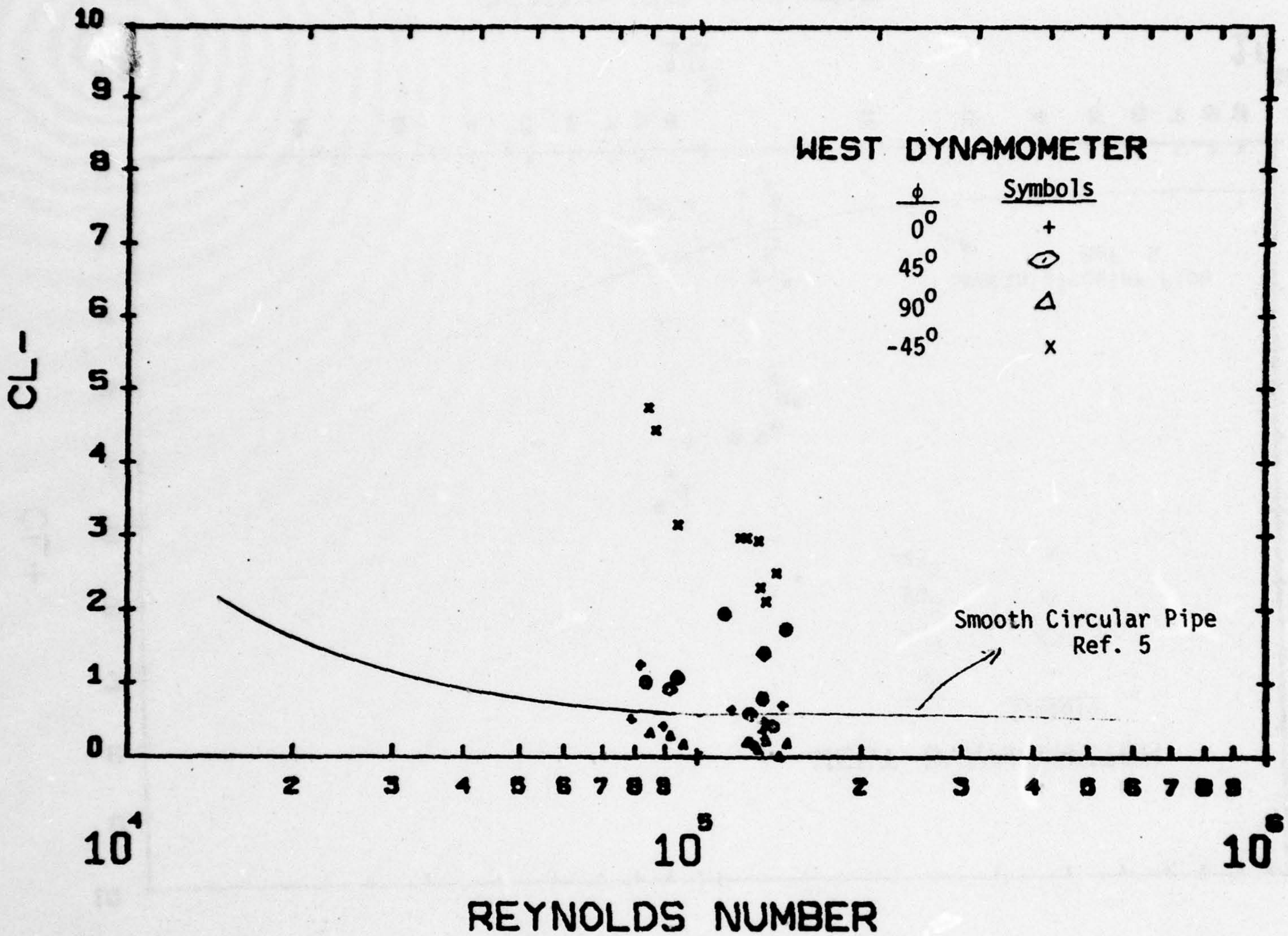

FIG. 71 - CL- vs. Re for all ϕs, K >20

71

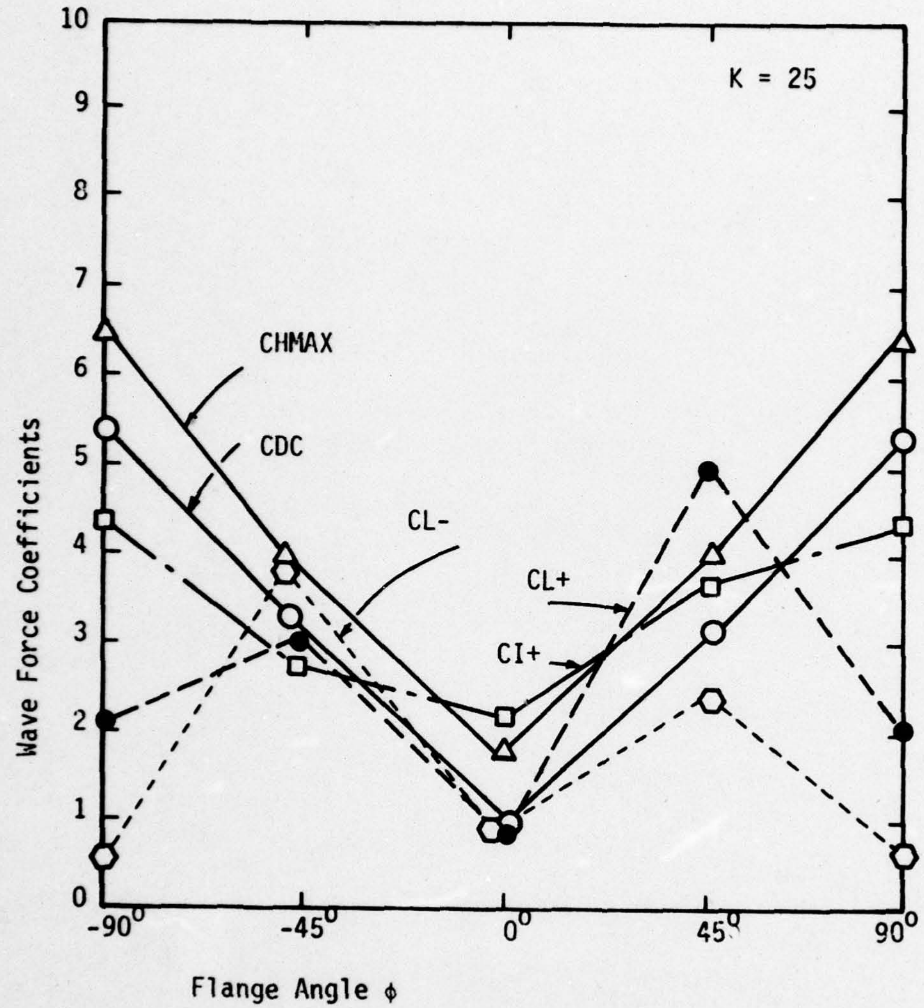

FIG. 72 - Force Coefficients vs. ϕ for K = 25